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DETERMINATION OF FRAGMENT IMPACT SENSITIVITY PREDICTION METHODS

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18. SUPPLEMENTARY NOTES

This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel. The primary objective of this (cont)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

4.2-inch HE mortar shell	Impact sensitivity
Air gun launcher	Secondary fragment impact
Ansys computer code	MMT-Protective technology
Finite element mesh	MMT-Safety engineering
Concrete fragment	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A two-part program was conducted that was both analytical and experimental. This report presents an analytical method for studying the mechanisms that lead to the detonation of cased munitions filled with molten explosives when impacted by large concrete fragments, representing failed wall sections. This is a single degree-of-freedom dynamic structural analysis method which makes use of predetermined, nonlinear load-deflection characteristics of the shell casing. In the analysis described, the method was applied to predict the pressure-time history in the molten explosive when subjected to impact. (cont)

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18. SUPPLEMENTARY NOTES (cont)

program is to develop a procedure, consisting of both experimental and analytical approaches, to better understand the mechanisms controlling the impact sensitivity of explosive-filled shells, and to develop a predictive capability to eliminate extensive testing on various shells in the future.

20. ABSTRACT (cont)

The experimental portion was performed to determine the credibility and accuracy of the predictive pressure-time history. A reasonable comparison between analytical and experimental results was obtained.

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INTRODUCTION

The U.S. Army, in trying to modernize and upgrade certain areas of munition production facilities, must assess internal and external structures of munition production facilities. In this modernization effort the Army is attempting to improve structures, equipment, safety and reduce and/or eliminate hazards. In one part of the modernization program, facilities are being assessed for their ability to prevent or limit propagation of an explosive accident. At one stage in the cast munition production process, molten explosives are poured into empty shell casings. At this, and most stages of the production process there is a finite probability that an accidental explosion may occur. To limit propagation of an accidental explosion, the pouring area is subdivided into smaller areas or bays separated by concrete walls. This does not completely eliminate the danger of propagation because an explosion in a cubicle can cause some breakup of dividing walls, producing energized fragments which may impact shell casings in neighboring cubicles thus possibly producing additional detonations. Whether or not an explosion is produced by such impact, depends on the dynamic pressures produced within the molten explosive, which in turn depends on the mass of the impacting fragment, its impact velocity, point and angle of impact, etc. The size of fragments produced by a separation wall depends on the physical characteristics of the wall, i.e. reinforcement details, concrete strength, aggregate size, thickness, span, support conditions, etc. It also depends on the intensity and distribution of the blast load produced by the donor charge on the dividing wall. It is important, if the dividing walls are to serve their intended purpose of preventing propagation of an explosion in adjacent bays, to determine the sensitivity of "just filled" shells to impact by broken up concrete wall fragments. Figure 1 depicts a "just filled" shell accidentally detonating and secondary fragments impacting an acceptor shell in an adjacent bay.

In the event of an accidental explosion, there will be some break up of the dividing wall. The extent of the break up (in terms of concrete fragment size and fragment velocity) will depend upon the details of the wall construction and the quantity of explosive that detonates. It is important, if the

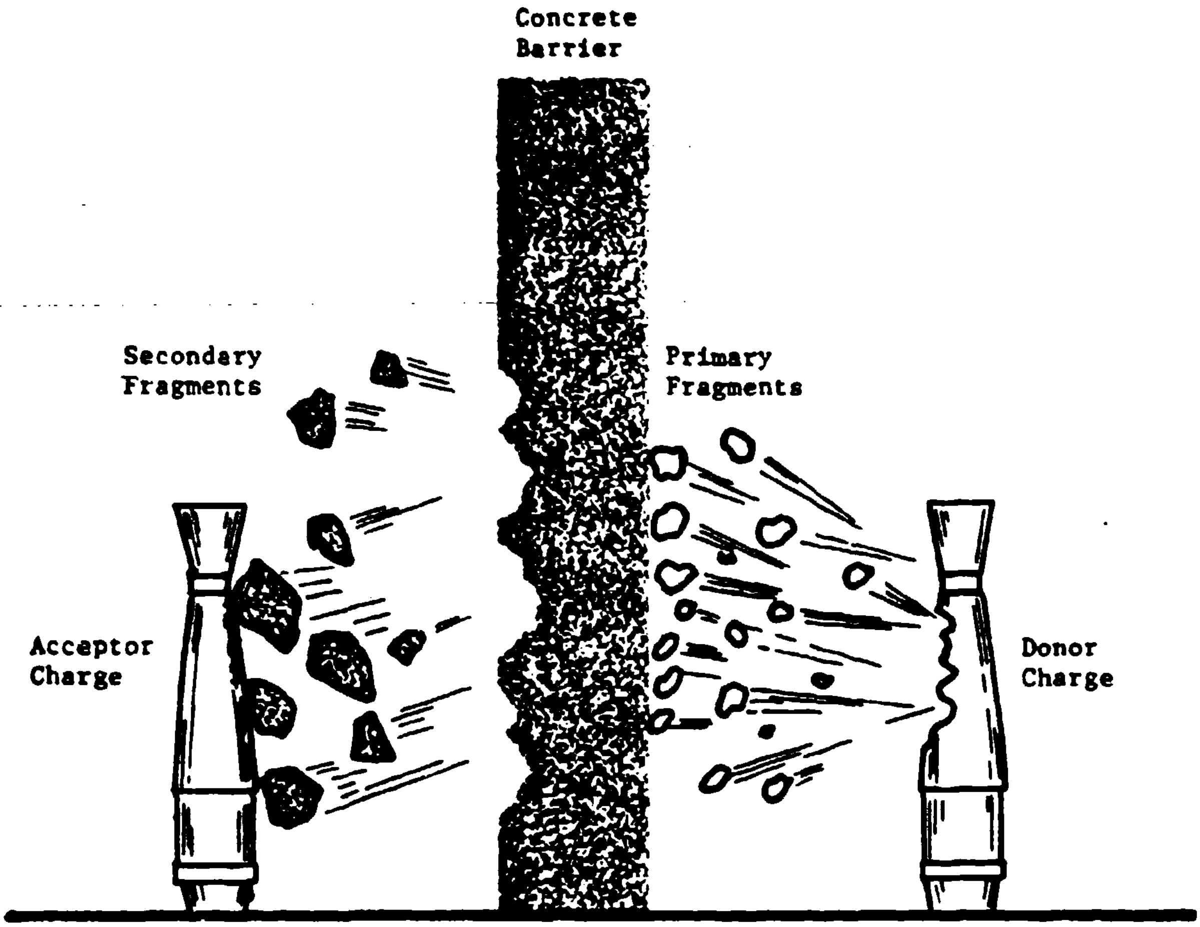

Figure 1 Schematic of Secondary Fragment Impact

dividing walls are to serve their intended purpose of preventing propagation of an explosion into adjacent bays, to determine the sensitivity of "just filled" shells to impact by broken up concrete wall fragments.

To date four experimental programs have been conducted to determine the sensitivity to impact by large concrete fragments of a variety of molten and ambient temperature explosive-filled shells, as well as the melt kettle (Refs. 1-4). These tests included the 4.2 inch, 81 mm, 120 mm, and 155 mm shells. They were filled with TNT, Composition B and/or Cyclotol 75/25, for a total of seven different shell-explosive combinations, plus temperature variations.

The four different shells tested covered a range of wall thicknesses, diameters, lengths and weights in order to obtain a spectrum of the types of shells that the U.S. Army manufactures. It was anticipated that the results of these tests would not only provide sensitivity data for the items tested (the primary objective of these test programs), but would also enhance predictions as to the sensitivity to concrete wall fragments for other items that were not tested.

In analyzing the data from these previous investigations (Ref. 4), several empirical sensitivity relationships were found which require limited testing to determine the sensitivity of an item. It was also clear from the evaluation, that making predictions was not simple because of the complex geometrics of the shells. The Army produces shell casings of various diameters, wall thicknesses, lengths and nose openings which causes the molten explosive to be extruded at different velocities, etc.

It was the objective of this program to develop a procedure, consisting of both experimental and analytical approaches, to (a) better understand the mechanisms controlling the impact sensitivity of explosive-filled shells, and (b) to develop a predictive capability so that extensive testing in the future would not be required.

TECHNICAL DISCUSSION

This discussion of the technical procedures utilized is divided into two parts. The first part deals with the analytical procedure and the second part deals with the experimental procedures. The objective of this program was to determine the mechanism controlling the impact sensitivity of molten explosive-filled shells when impacted by secondary fragments. To accomplish this objective an analytical effort was performed which allowed a better understanding of the response of a shell casings, as well as the shell interaction with the explosive to cause it to develop the high pressures and temperatures leading to explosions. Next, in order to determine the credibility and accuracy of the analysis, instrumented experiments were conducted to obtain data and to provide insight as to what was occurring during the impact process. Analyses were used to describe features that were not easy or even possible to measure experimentally. On the other hand the experiments did provide sufficiently accurate data to verify the analysis. All experiments were instrumented and the impact tests were performed using a 12 inch diameter air gun. Cylindrical concrete projectiles, which simulated broken up wall fragments, were used to impact shell casings filled with a fluid simulating the molten explosive.

ANALYTICAL PROGRAM PROCEDURES

A schematic showing the shell-fragment configuration is depicted in Figure 2. A shell casing, open at its apex, is assumed to be sitting stationary. This casing is completely filled with either an explosive at a sufficiently high temperature to be in a liquid state or some simulated solution duplicating the molten explosive of interest. The fragment, a concrete cylinder is moving in a horizontal direction at a velocity, V. Upon impact, the conditions are assumed to be such that the shell casing will be plastically deformed and will experience an acceleration. The plastic deformation of the shell casing will cause the liquid explosive to be pressurized and thus forced to flow up and through the filling orifice at the apex of the casing. This pressure build-up during the time of impact is hypothesized to be a good measure for determing if the explosive will detonate. This is because there will be at least two effects

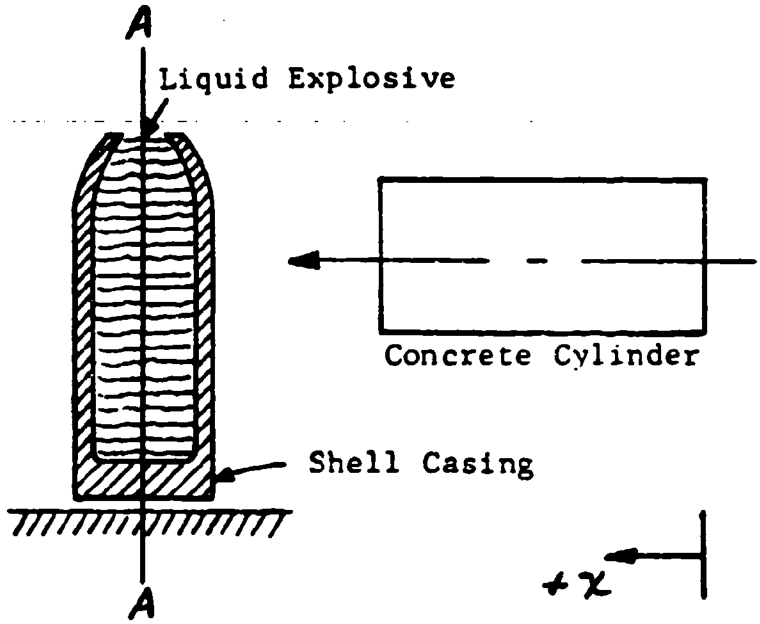

Figure 2 Shell-Fragment Configuration

that will occur as a result of pressure build up. First, as the pressure increases so will the temperature of the fill and secondly the extrusion or flow at high velocities through the orifice, as a result of the deformation induced pressurization, will lead to high temperatures of the material in the orifice area (Ref. 5, 6 and 7). The analytical procedure used to obtain the liquid explosive pressure versus time relationship during impact is described in the following paragraphs.

The analytical solution is a single-degree of freedom dynamic analysis which requires certain postulated explosive - shell casing - fragment interaction characteristics which are the following:

1) Force versus deflection characteristic (resistance function) of the shell casing

2) Volume versus deflection characteristic of the shell casing

3) Orifice area versus deflection characteristics of the shell casing

4) Internal pressure versus molten explosive volume flow rate characteristics

For the purpose of determining the force-deflection characteristics, the shell casing can be assumed to be restrained in the horizontal, X direction only, all along a line formed by the intersection of the midplane of the shell surface and the vertical plane whose edge view can be indicated by the line A-A in Figure 2. A finite element computer code, which met the requirements of large deflections and plastic deformation of the casing material was selected. The code selected, ANSYS (Ref. 8), is a fully documented standard finite element code widely used in structure analysis. To obtain the first three steps of this procedure a series of selected deformations are applied to the shell casing and the internal pressure with the corresponding forces required to produce them are calculated. Typical expected curves for these characteristics are shown in Figures 3, 4 and 5.

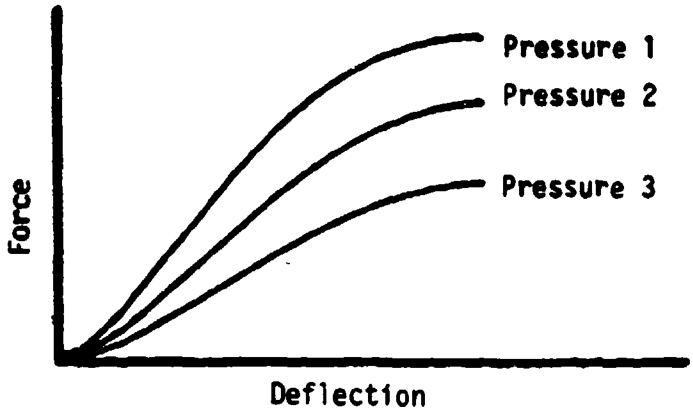

Figure 3 Typical Force-Deflection Curves

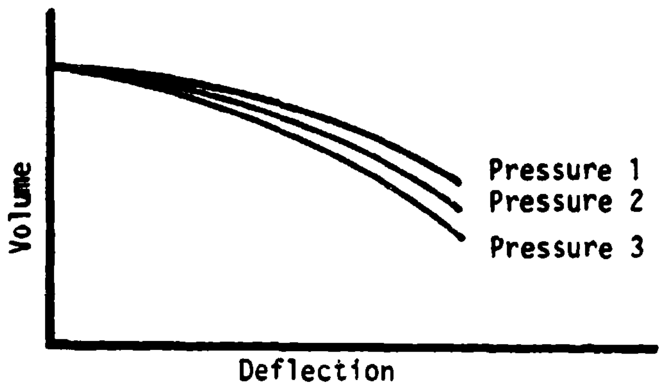

Figure 4 Typical Volume-Deflection Curves

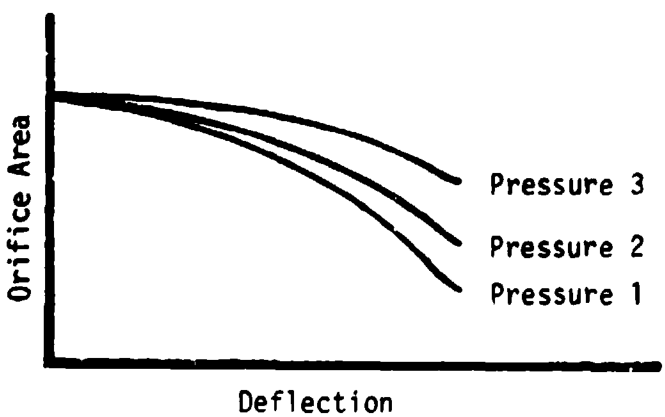

Figure 5 Typical Orifice Area-Deflection Curves

Finally, the concern is with the flow characteristics of the liquid explosive through the orifice of the casing. The flow is dependent on the orifice area, the fluid pressure, viscosity, and the orifice coefficient. The following formula (Ref. 9) was used to relate the flow rate, Q to the internal pressure, p of the liquid explosive and other parameters:

$$Q = C_c A \sqrt{2gp/\gamma} \tag{1}$$

where

C_c = the orifice coefficient

A = the orifice area

g = acceleration due to gravity

γ = weight density of the liquid explosive

Typical expected flow characteristics are shown in Figure 6 for three orifice areas.

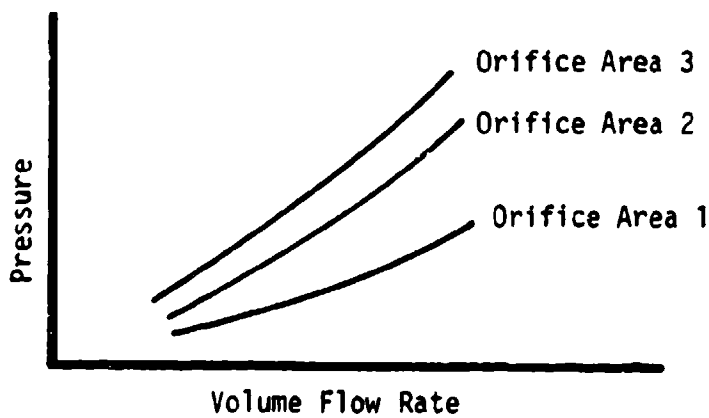

Figure 6 Typical Flow Rate Curves

Referring to Figure 2, assuming that the concrete cylinder and the shell move in a straight line, the equations of motion and initial conditions are as follows.

$$M_c \ddot{X}_c = -F \tag{2}$$

$$M_s \ddot{X}_s = F \tag{3}$$

where M_c and M_s represent the mass of the cylinder and the shell respectively. F is the interaction force between the shell and the concrete cylinder, and $\ddot{X}_c$ and $\ddot{X}_s$ are the center of gravity accelerations of the concrete cylinder and the shell respectively.

The initial conditions for the concrete cylinder and the shell are (at t=o, impact is initiated) $\dot{X}_c$, the initial velocity of the cylinder is equal to V, $\dot{X}_s$, the initial velocity of the shell is equal to zero. The initial displacements, X_c and X_s of the cylinder and the shell are respectively equal to zero. If the interaction force, F, is known at any time, t, the accelerations can be determined and the velocities and displacements at some small interval of time later, Δt, can be approximated using Euler equations of the integration process, i.e.

$$\dot{X}(t + \Delta t) = \dot{X}(t) + \ddot{X}(t)(\Delta t) \tag{4}$$

$$X(t + \Delta t) = X(t) + \dot{X}(t)(\Delta t) \tag{5}$$

Table 1 presents the technique used to obtain the liquid explosive pressure versus time curve utilizing the procedures presented above.

TABLE 1 SOLUTION PROCEDURE

1. Read data describing the system.
2. Set time to zero (t=o) and displacements and velocities to their initial values. Set initial internal pressure to zero, and the orifice area and the casing volume to the initial values.
3. Print out time and pressure.
4. If time exceeds maximum value, stop.
5. From force-deflection-pressure curves determine the interaction force, F. Note that the casing deflection δ, is the difference in the cylinder and shell motions (displacements), i.e. $\delta = X_c = X_s$.
6. Compute cylinder and shell accelerations, use equations (2) and (3).
7. Use the Euler integration formulas, equations (4) and (5), to determine velocities and displacements of the cylinder and the casing at time $t + \Delta t$. Update time to $t + \Delta t$.
8. Determine shell casing volume using volume-deflection-pressure curves. Compute volume rate of flow from difference in volume from previous time step divided by time step, Δt.
9. Determine orifice area from orifice area-deflection-pressure curves.
10. Determine new internal pressure from press-volume-flow rate-area curves.
11. Determine the change in pressure over the time step Δt and compute the change in the weight density of the liquid explosive.

12. Determine the new weight density.

13. Determine the change in volume due to the change in the weight density. Compute the volume rate of flow. Continue the iteration until the change in volume is smaller than a preassigned value.

14. Return to step 3 and continue.

Note steps 11 through 13 represents an iterative procedure that is used to take into account the compressibility of the liquid explosive.

EXPERIMENTAL PROGRAM PROCEDURES

Target Description

A decision was made to analyze and experiment with the 4.2 inch mortar shells. This selection was based on the fact that this munition was tested previously, plus has an average wall thickness in the mid-range of wall thicknesses being analyzed (0.50 to 0.58 cm (0.198 to 0.230 inches thick)), and has an average threaded opening at the top (2.0-12UN-1B). Figure 7 depicts the selected munition for analysis and experiments.

Originally it was planned to use 4.2 inch H.E. mortar shells filled with Composition B explosive. However, this was changed to using shells filled with some fluid having the same viscosity as molten Composition B. The idea was to prevent a detonation to occur during the impact test, so that the casing can be retrieved in one piece. Instead, using a fluid such as Glycerol or oil, with the proper viscosity, guaranteed that the shell casing would remain in one piece after each impact test. Therefore, allowing visual inspection of the casing after the test for comparison to the finite element predicted plot obtained by the analytical analysis.

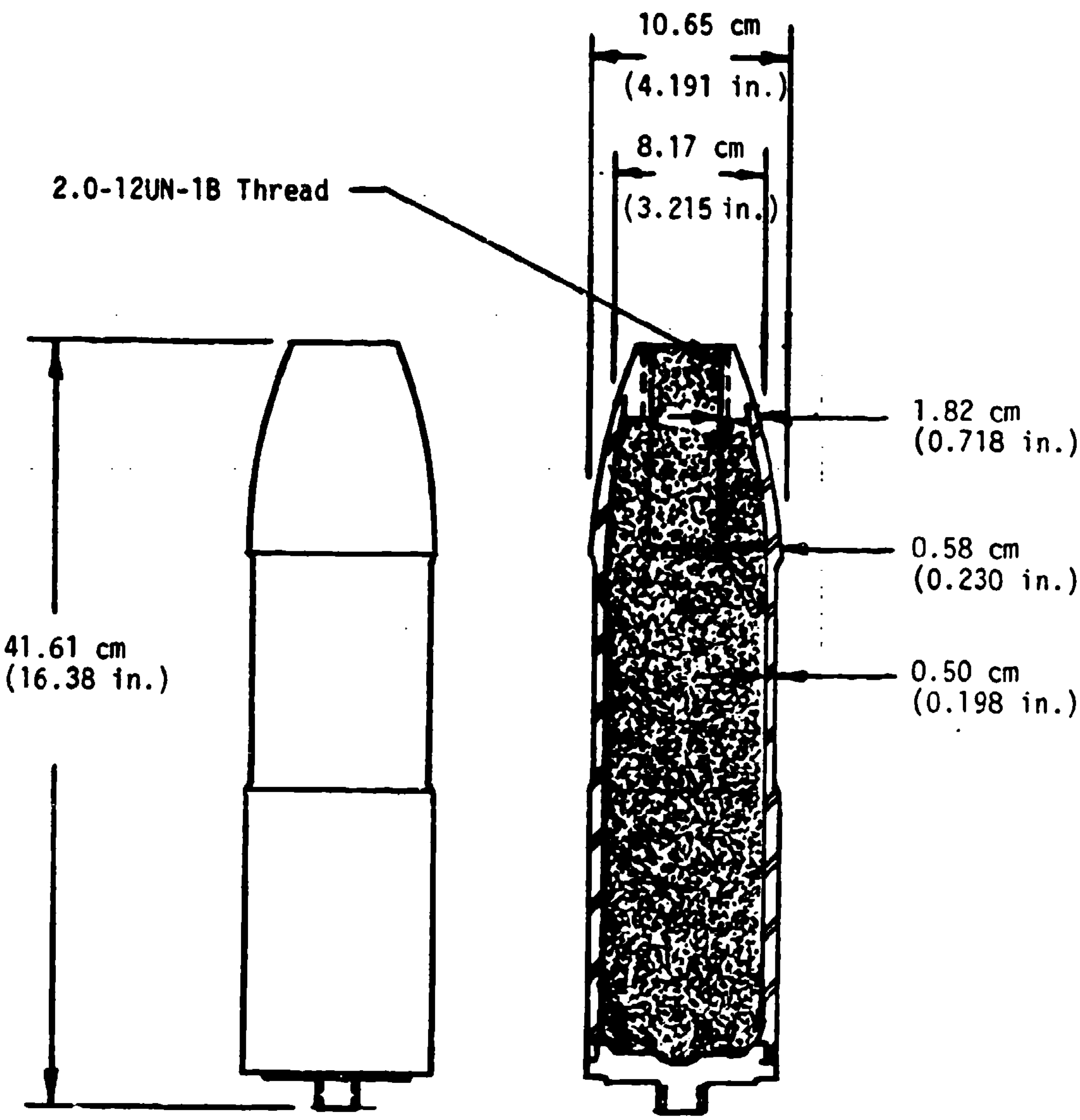

Figure 7 4.2 Inch H.E. Mortar Shell

Pouring viscosity of Composition B is 270 centipoise at 95°C (203°F) and 310 centipoise at 83°C (181°F) (Ref. 10). A solution of Glycerol and water to attain a 300 centipoise viscosity solution at an ambient outdoor temperature was utilized. Note that the melting point of Composition B is at 78° to 80°C (172° to 176°F). This solution was selected since it was fairly easy to maintain its viscosity at 300 centipoise at various temperatures between -3°C (27°F) to 25°C (75°F).

To maintain this viscosity at various temperatures two graphs were developed for the viscosity of the Glycerol solution. See Figures 8 and 9 depicting viscosities of Glycerol and water solution. From these graphs one can find the percent by weight of Glycerol and water necessary to maintain a constant viscosity of 300 centipoise at the various outdoor temperatures.

A description of the experimental methods employed to obtain data under secondary fragment impact conditions and the test procedures followed, appear in this section of the report.

The most vulnerable conditions in the melt loading operation (with regard to secondary fragment impact) is when the molten explosive has been poured and is sitting in the shell casing at an elevated temperature. The munition in this state can accidentally detonate producing secondary concrete fragments in adjacent bays. To simulate these conditions a test setup for impact experiments as depicted in Figure 10 was developed. All 4.2 inch H. E. mortar shell targets tested on this program had simulated fluid in them, except for the final experiment (Experiment 9) which utilized molten explosive. Following is a list of the experiments performed:

- Steel tubing (4 inch outside diameter) 15.5 inches long filled with sand, three tests performed (practice tests)
- 4.2 inch mortar shell filled with Glycerin and water solution, five tests performed
- 4.2 inch mortar shell filled with molten explosive, 1 test performed.

The summary of the pertinent information on the target shell and practice target tubing is shown in Table 2.

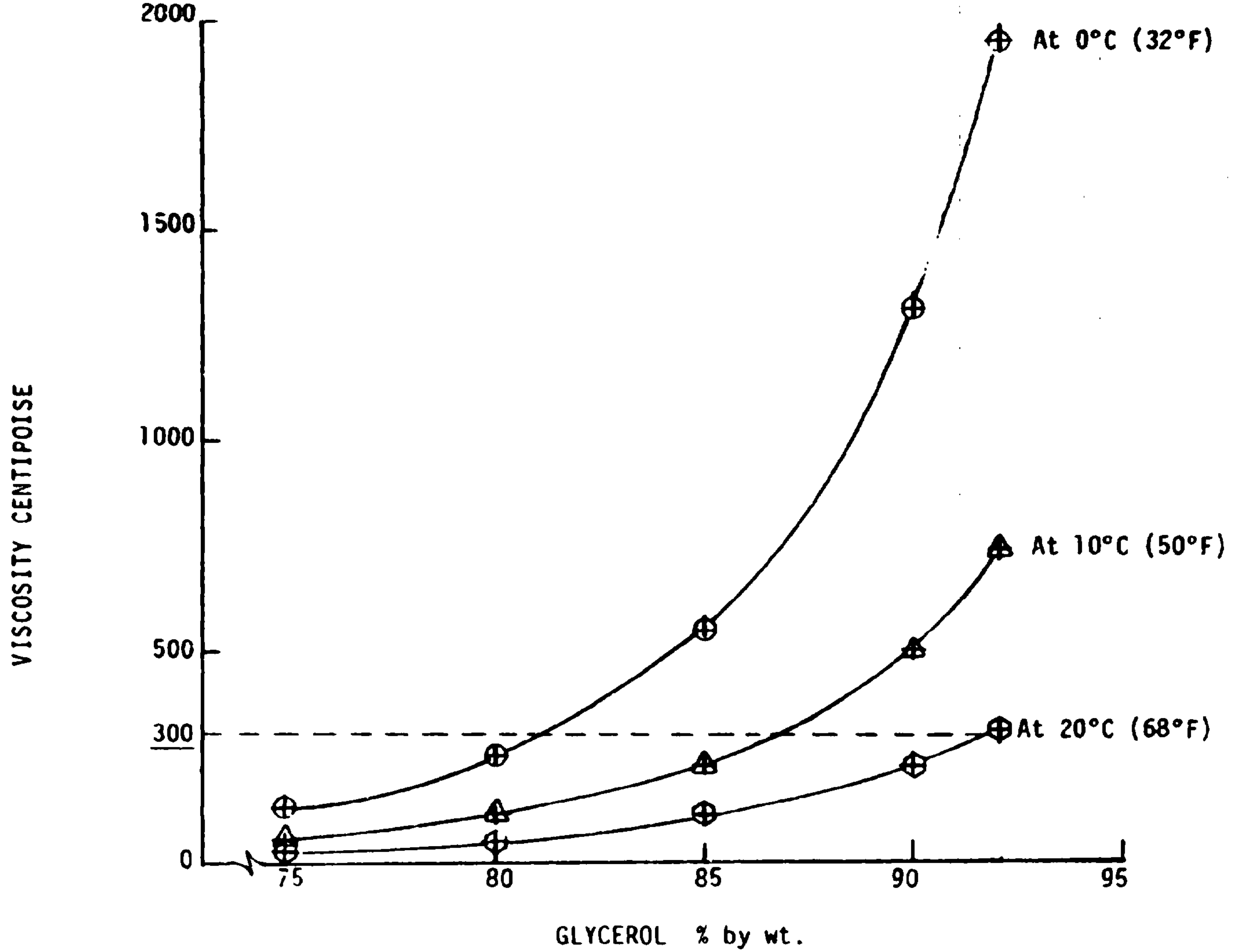

Figure 8 Viscosity of Glycerol Solutions

(Ref. 11 Handbook of Chemistry and Physics, 44th Edition, p 2273)

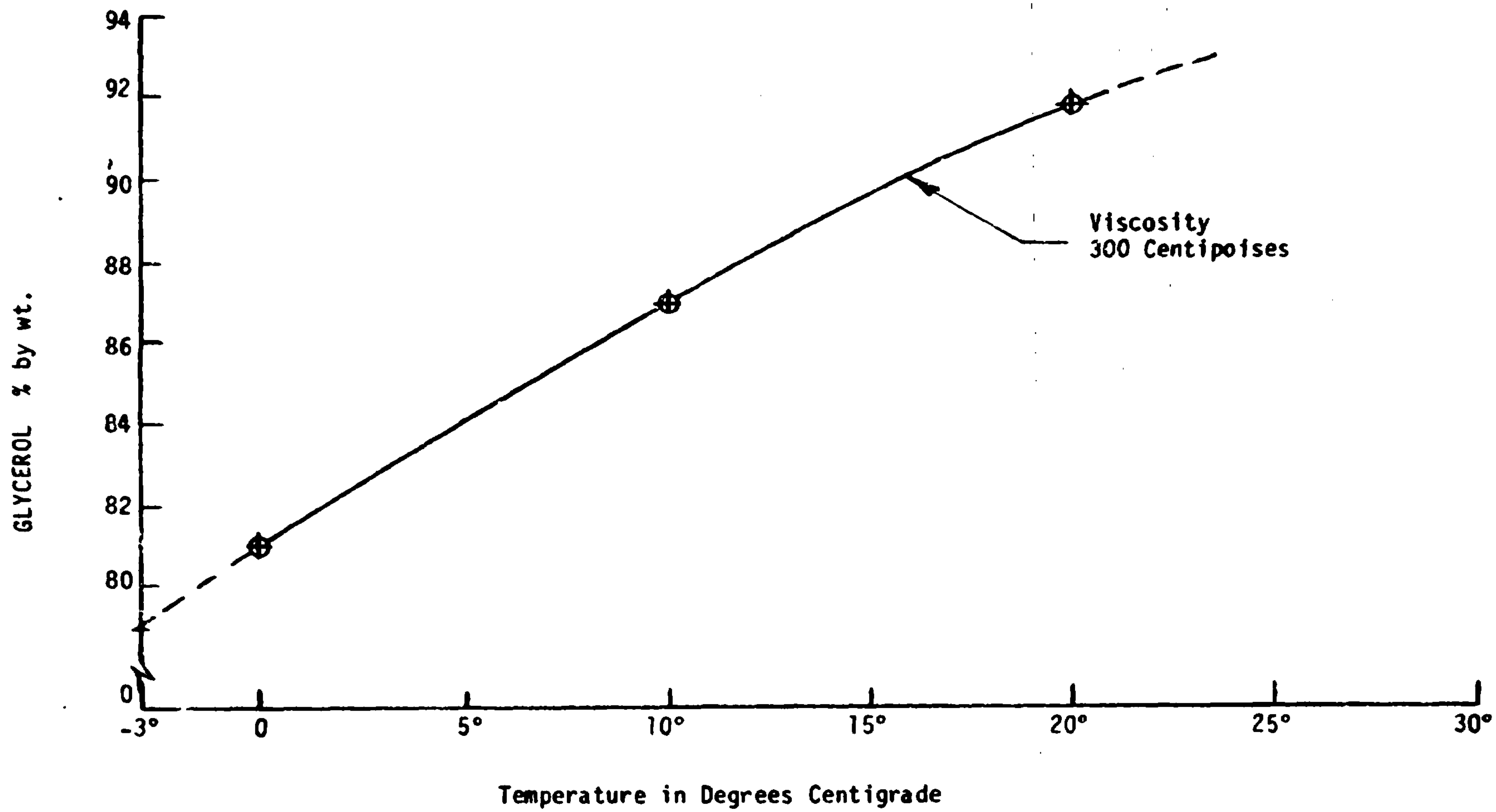

Figure 9 Percent of Glycerol Necessary to Maintain a Constant Viscosity (300 Centipoises)

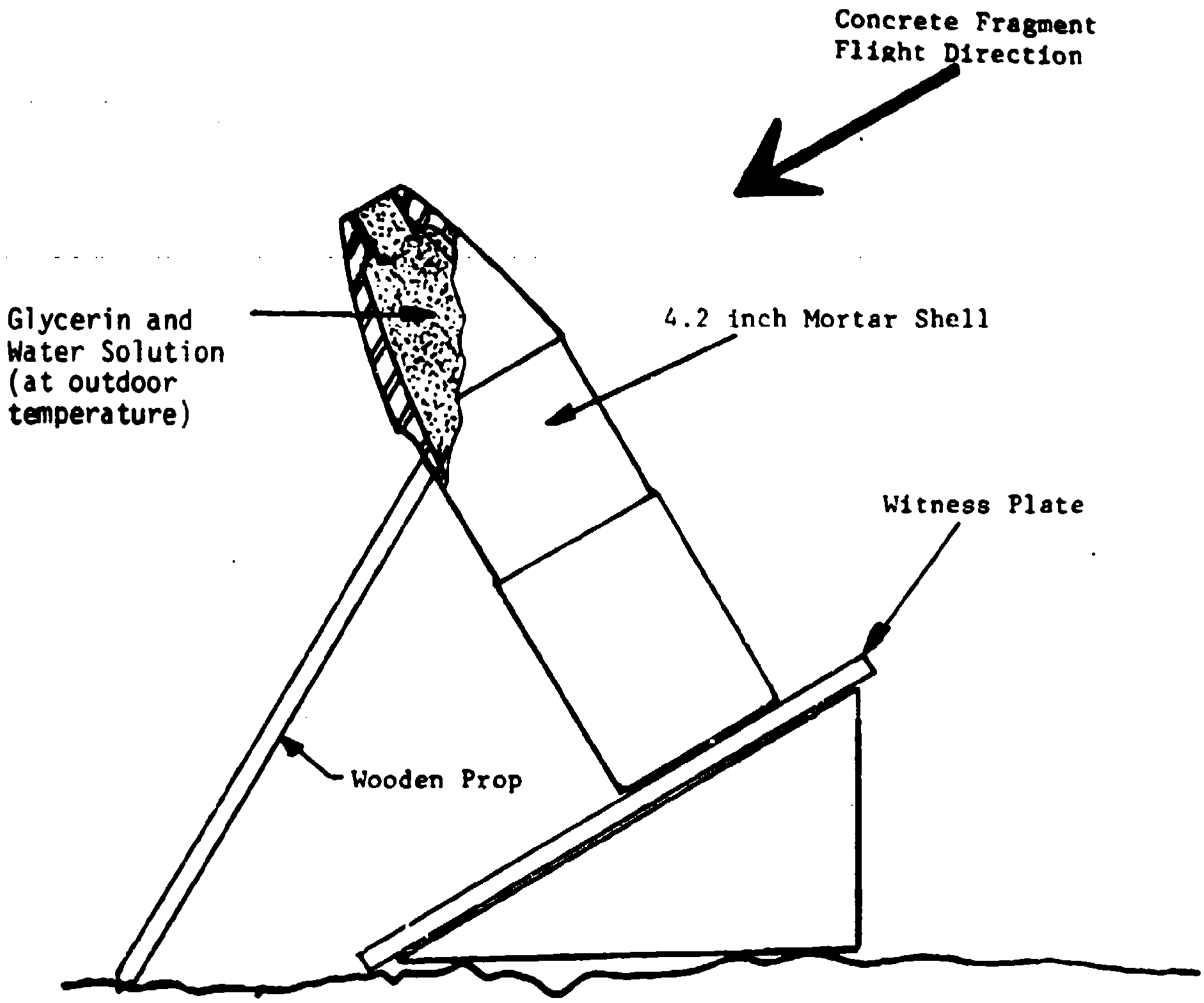

Figure 10 Test Setup of a Shell for Impact Testing

TABLE 2. ACCEPTOR TARGETS OF SECONDARY FRAGMENT IMPACT TESTS

	Steel Tubing Sand Filled	4.2 inch Mortar Shell
Explosive weight	None	3.5 kg (8 lb)
Shell casing weight	NA	6.8 kg (15 lb)
Wall thickness at maximum diameter	3.18 mm (0.125 in.)	6.58 cm (0.23 in.)
Maximum diameter	101.6 mm (4.0 in.)	10.65 cm (4.191 in.)
Maximum wall thickness	NA	1.82 cm (0.718 in.)
Diameter at maximum wall thickness	NA	8.17 cm (3.215 in.)
Explosive/case weight , E/C	NA	0.51
Wall thickness/maximum diameter, t/D_{max}	0.031	0.055
Maximum wall thickness/diameter, t_{max}/D	0.031	0.223

Concrete Fragments

Laced reinforced, and in some cases just concrete elements and/or barriers without lacing are used in structures designed to resist the explosive force of a high order detonation. Generally a high early strength Portland cement with a maximum strength of 20,684 kPa (3000 psi) (Ref. 12) is used in structures. To minimize the effect of spalling, the size of the aggregate is limited to less than 2.54 cm (1 inch). The concrete used in this program to simulate wall fragments was a nine bag mix of Portland cement with aggregate size less than 2.54 cm (1 inch). All concrete projectiles were left in ambient air for at least 7 days to cure before being expended.

The simulated concrete wall fragments were fabricated from cardboard cylinders, which were cut in two lengths. Certain length to diameter ratio as well as weights were maintained for these test series. Figure 11 shows the cardboard tube assemblies into which the concrete was poured. This shape was selected to facilitate launching these concrete fragments from the high pressure air gun. The obturator mounted on the back side of the concrete fragment was of (high density) polyethylene and provided a good seal with the barrel on the air gun. Only two nominal sizes and weights of the concrete fragments were used in this program, namely 0.61 m and 1.22 m (2 ft and 4 ft) long that weighed 90.7 kg and 181.4 kg (200 lb and 400 lb) respectively.

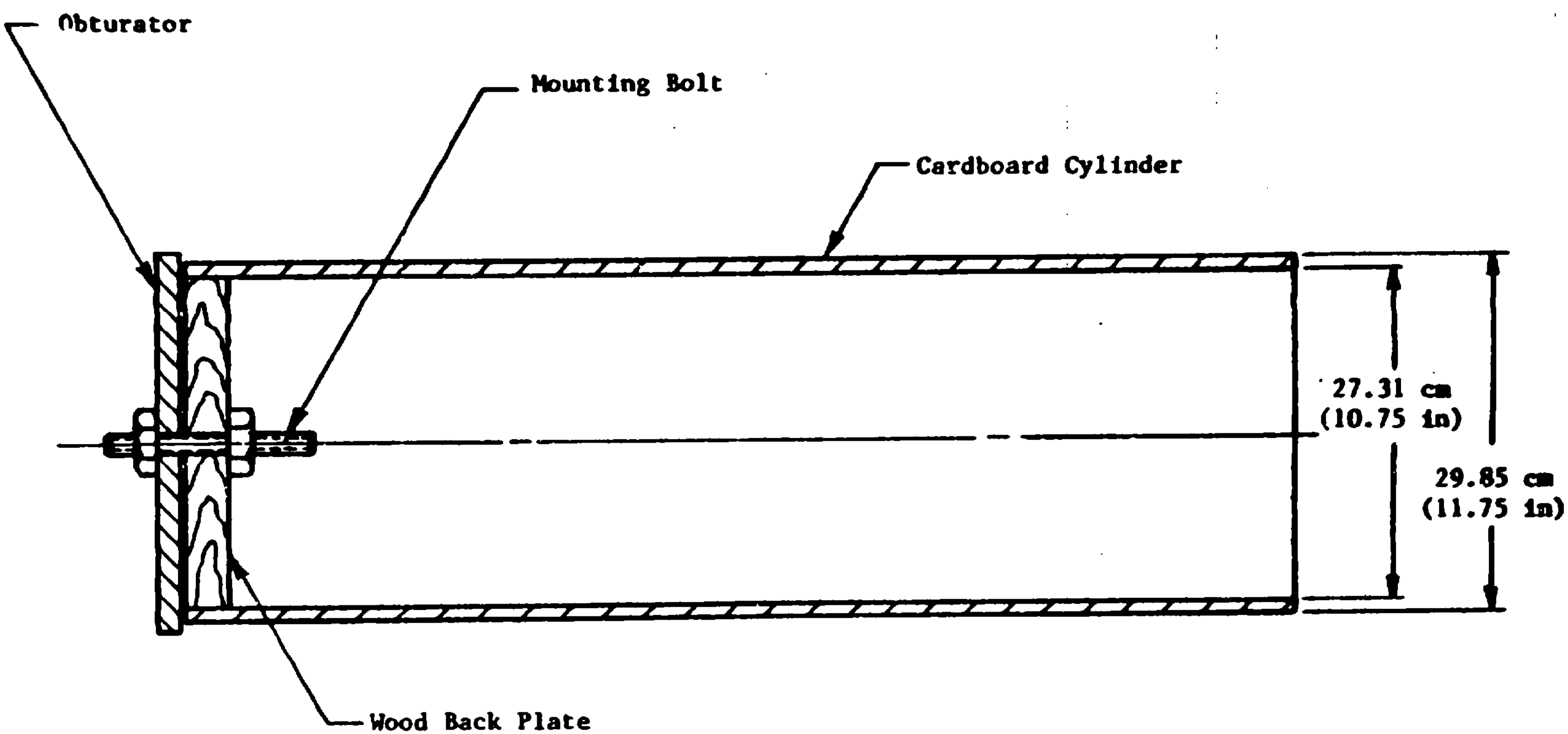

Figure 11 Concrete Fragment Container Assembly

Air Gun Launcher

A high pressure air gun was used to launch the cylindrical concrete fragments at the targets. Figure 12 shows the gun's arrangement relative to the targets. The capabilities of the air gun are shown in Figure 13. A maximum chamber pressure of 17,237 kPa (2500 psi) is normally selected for safe operation. With this limitation the maximum velocities for the smaller weight concrete projectile can be around 335 m/sec (1100 ft/sec) and for the heavier weight projectile around 152 m/sec (500 ft/sec). Some differences have been observed between the velocities selected and the velocities obtained, and it has been concluded that these differences are due to wind effects on the fragments in flight and the friction between the fragment and the gun barrel as the fragment is being propelled out. Aiming of the gun was done with a laser placed in the barrel. The target was then moved to the desired position and the laser removed before firing. A compressor pumps air into a large holding vessel and this compressed air is then bled into the gun chamber prior to firing. The charging and firing of the gun is done remotely.

Experimental Tasks

In this program, normally one experiment could be conducted daily if all supporting items were on hand. The shells for this program were received filled with TNT explosive. To prepare the shell for a test all explosives had to be melted out of the shell casing, and then the empty shells were scribed with a 1 inch grid. The grid was necessary to help with visual inspection of the shell after impact and to make comparison of the impacted results to the finite element prediction obtained by the analysis.

Each target shell was filled with the Glycerol solution such that its viscosity was 300 centipoise at that day's outside temperature. Knowing the outside temperature the proper glycerine and water proportions (percent by weight) were mixed and colored with red food coloring so as to better show up on the color high speed film. As the shell was being prepared so was the air gun being prepared for firing. Each concrete fragment was weighed just before placing it into the gun barrel to an accuracy of $\pm$ 2.27 kg ($\pm$ 5 lb).

A wooden test stand was fabricated so that the target shells were positioned perpendicular to the flight of the concrete fragment projectile. Also, the shells had to be propped up with a board so as not to tumble. See Figure 10

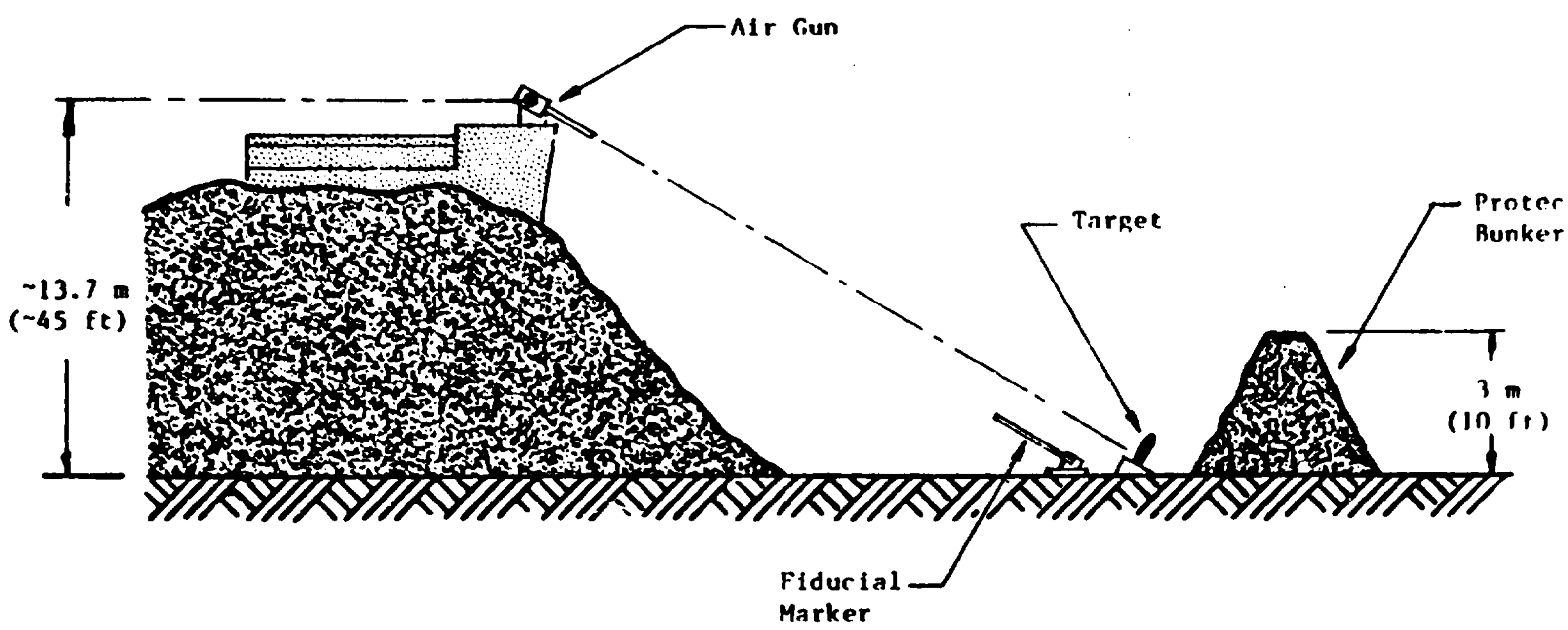

Figure 12 Secondary Fragments Impact Test Site

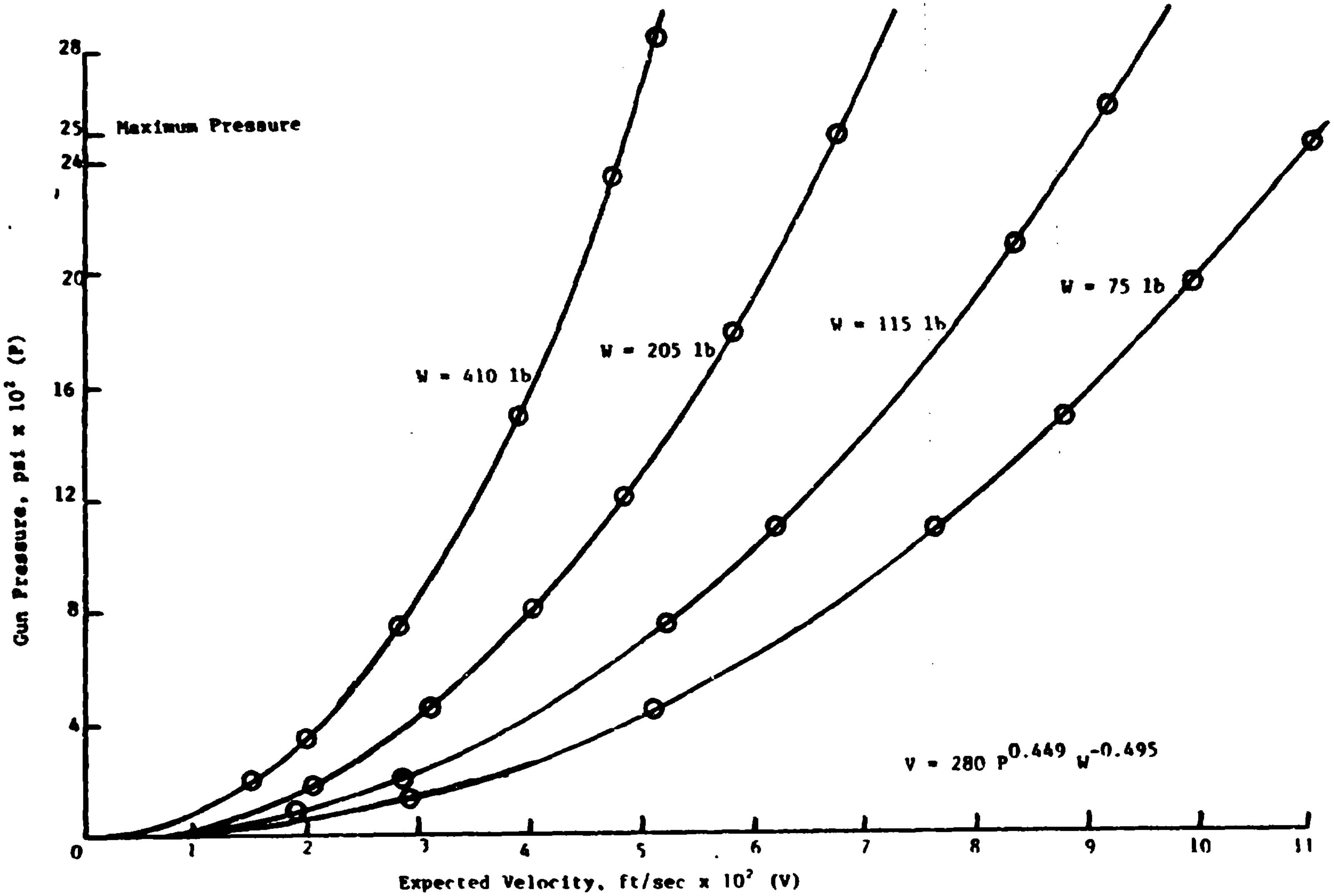

Figure 13 Air Gun Capability

depicting the angled stand and the prop. A 2.54 cm (1 inch) thick steel witness plate 30.48 cm x 30.48 cm (12 inch x 12 inch) was used beneath the targets. In this witness plate a hole was cut to accommodate the threaded studs on the bottom of the 4.2 inch mortar shell target.

Concrete fragment velocities were determined from film records of each experiment. A fiducial marker with 30.48 cm (12 inch) increments was placed in the field of view of the cameras. Two high speed Fastax cameras operating at approximately 3000 frames/sec,peak,were used to film each event.

In the experimental setup an aluminum foil switch was attached to the target's outer surface with fiberglass tape and signalled when the concrete projectile made contact with the target. Also to pick up the fluid pressure increase upon impact from the concrete projectile a pressure gage was lowered into the Glycerol solution. A PCB Piezotronic, Incorporated, Model No. 113A23 pressure sensor was employed. This sensor model has a quartz sensing element with a built in low-noise amplifier. It was held in place through a polystyrene acoustical decoupler as a technique for eliminating the ringing of the gage. The pressure gage was located approximately 25.4 cm (10 inches) from the top of the shell. Lastly the outdoor test site temperature was recorded to aid the technicians in mixing the proper percent by weight of Glycerin and water to attain a viscosity of 300 centipoise.

Time pressure traces of four of the nine tests were recorded on the explosive simulated mixture during the impact sequence.

Figure 14 illustrates the pressure measuring system, set up for these impact experiments in block diagram form. The purpose of the total system was to monitor the transient pressure wave, P(t), and provide an electrical analog recording $E_0 = F(P(t))$. The system had to have a fairly demanding frequency response, linearity, and a high signal-to-noise ratio so as to produce an acceptable analog of the impact applied pressure.

The transducer, with its coupling to the shell and its response to the fluid in the shell, could contribute to experimental error; therefore, the transducer was mounted so that it was isolated from the ringing influence of the gage by a polystyrene adapter. However, the transducer was placed down into the Glycerol solution in the target shell which was impacted by large concrete fragements.

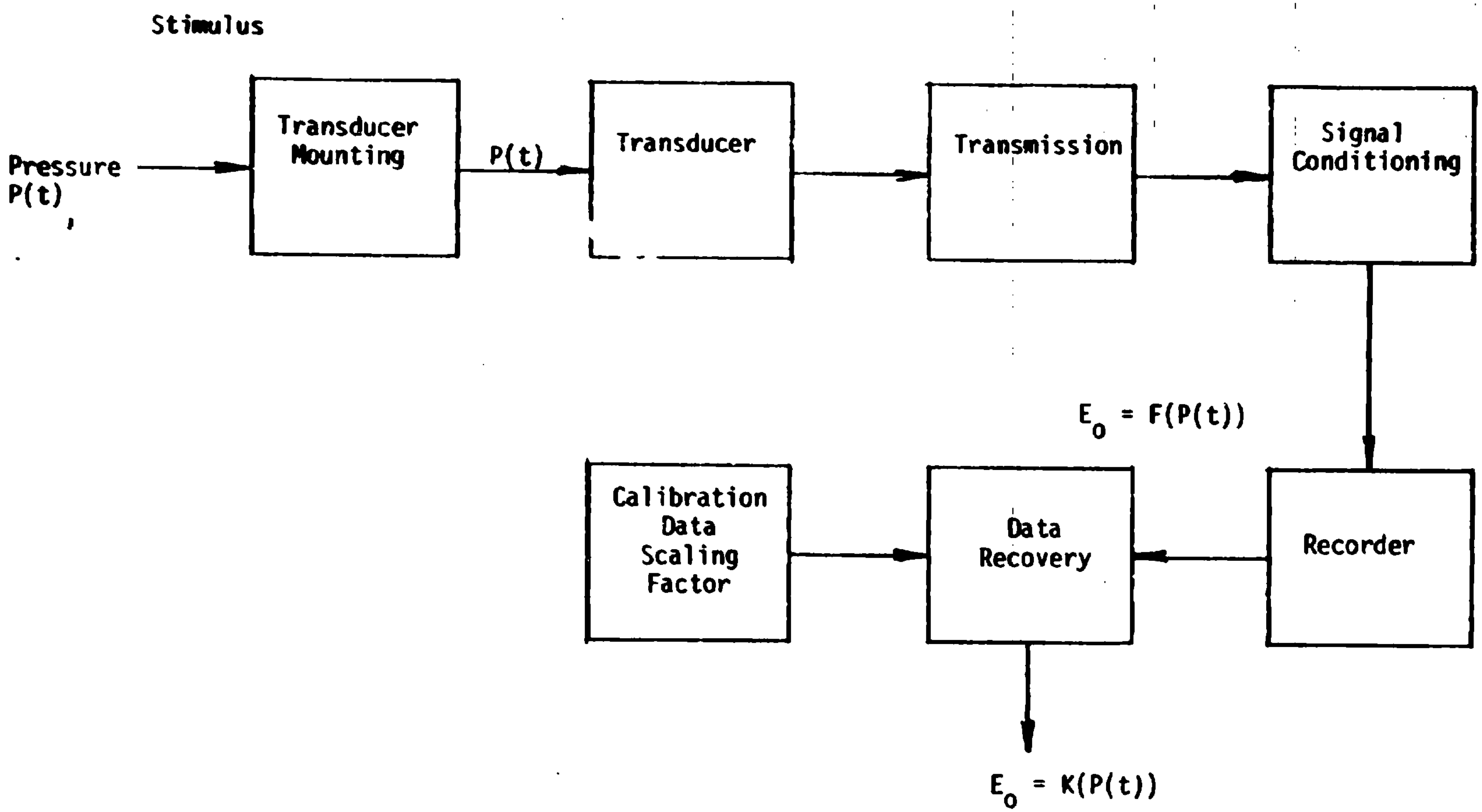

Figure 14 Block Diagram of a Pressure Measuring System

A general purpose quartz dynamic pressure transducer with a 20,000 psi range maximum pressure was utilized. The selection of the transducer was based on the calculated frequency response (rise time), sensitivity, and dynamic range.

The transmission equipment used included: built-in electronics, impedence matching networks, conventional transmission lines and the stimulus power supply. This system transmitted the transducer signal to the signal conditioning equipment without too serious degradation of the shape or undue increase in the noise level. The following procedures were followed:

- the transmission line was of low capacity/foot (RG 62A/U) and was as short as practical
- the stimulus voltage was the maximum rated current for the transducer (20 ma)
- the signal voltage was as low as possible - consistent with an acceptable signal-to-noise ratio of 1.0 volt peak

The instrumentation was set up so as to give a good resolution of the pressure and time curves for each impact test. After each test the pressure transducer had to be located (which was buried in sand by the impact of the concrete fragment), cleaned, recalibrated, and rewound in preparation for the next test.

The instrumentation was attached to a magnetic tape recorder, IRIG Wideband II, with numerous selected data channels, each with a different amplitude, to capture the entire amplitude of the pressure curve.

EXPERIMENTAL RESULTS

In this portion of the report the raw experimental data are presented. These include dimensions of the shell deflection, visual observation of the targets together with the analysis from the film records of the concrete projectile velocity, location of hit, and impact results. Some still photos were scrutinized. An overall summary of the experimental results is found in Table 3. For complete information on the experiments,refer to Field Data Sheets and still photos in the appendix. Each experimental event has been recorded on high speed film. The first section of this portion of the report presents the method used to determine the velocity of the concrete fragment projectile. Subsequent sections present the analysis and the results of this program's analytical and experimental tasks.

TABLE 3. SUMMARY OF THE EXPERIMENTAL DATA

Test Number	Date	Outdoor Temperature	Gun Chamber Pressure	Target	Fragment Size	Fragment Velocity	Maximum Deflection (Approx. Scaled Dimension)	Results
1	11-30-81	3.3°C (38°F)	1931 kPa (280 psi)	Steel tube filled with sand	90.7 kg (200 lb)	84.7 m/sec (278 ft/sec)	-	Concrete projectile missed target hit to the right and low (practice)
2	12-01-81	-	1999 kPa (290 psi)	Steel tube filled with sand	90.7 kg (200 lb)	88.1 m/sec (289 ft/sec)	-	Concrete projectile hit at proper height but a little to the left (practice - see still photos in appendix)
3	12-01-81	8.9°C (48°F)	1931 kPa (280 psi)	4.2 inch shell filled with Glycerin solution	90.7 kg (200 lb)	85.0 m/sec (279 ft/sec)	3.61 cm (1.42 in.)	Concrete projectile hit at desired location (see still photos in appendix)
4	12-02-81	3.9°C (39°F)	1931 kPa (280 psi)	4.2 inch shell filled with Glycerin solution	90.7 kg (200 lb)	82.9 m/sec (272 ft/sec)	3.18 cm (1.25 in.)	Concrete projectile hit at desired location (see still photos in appendix)
5	12-03-81	-	8274 kPa (1200 psi)	Steel tube filled with sand	90.7 kg (200 lb)	131.7 m/sec (432 ft/sec)	-	Concrete projectile hit at desired location (practice)
6	12-04-81	6.7°C (44°F)	2874 kPa (1200 psi)	4.2 inch shell filled with Glycerin solution	90.7 kg (200 lb)	160.9 m/sec (528 ft/sec)	Bent 90°	Concrete projectile hit at desired location (see still photos in appendix)
7	12-09-81	-1.1°C (30°F)	2413 kPa (350 psi)	4.2 inch shell filled with Glycerin solution	181.4 kg (400 lb)	67.1 m/sec (220 ft/sec)	3.3 cm (1.3 in.)	Concrete projectile hit at desired location (see still photos in appendix)
8	12-10-81	0°C (32°F)	1931 kPa (280 psi)	4.2 inch shell filled with Glycerin solution	90.7 kg (200 lb)	88.1 m/sec (289 ft/sec)	in pieces	Concrete projectile hit at desired location, a little low - shell broken into pieces (see still photos in appendix)
9	12-11-81	2.2°C (36°F)	1931 kPa (280 psi	4.2 inch shell filled with TNT	90.7 kg (200 lb)	85.6 m/sec (281 ft/sec)	2.16 cm (0.85 in.)	Concrete projectile hit at desired location, base of shell missing - some solidified TNT left in nose of shell - hit a little low (see still photos in appendix)

Secondary Fragment Velocity Determinations

Velocities were determined from the high speed film records obtained. The first step was to calculate the film speed at the event. This was accomplished by the following procedure and equation:

- measure a number of frames to obtain arithmatic average of film frame size (F_a in cm)
- measure a length over some selected number of timing spots (L in cm)
- selected number of timing spots (N_t) (note each timing spot represents 1 msec)

$$\text{Film speed} = V_f = \left(\frac{L}{F_a N_t}\right) \cdot \left(\frac{1}{10^3}\right) \text{ frames/sec} \qquad (1)$$

Next the event had to be observed over a selected projected length on the fiducial marker and the number of frames counted for the fragment to traverse this length. The position of the fiducial marker required that two types of corrections had to be made for the projectile displacement. One correction was made because the marker was in front of the centerline of the concrete fragment path. The second because the angle at which the fiducial marker was placed was slightly different from that of the fragment flight path. The following equation made the necessary corrections of the projected displacement:

$$\text{Corrected Projected Displacement} = \Delta X = \left[\frac{d_c}{d_f}\right] \cdot \left[\cos\left(\alpha_2 - \alpha_1\right)\right] \qquad (2)$$

where d_c is the distance from the camera to the centerline of the fragment path (in this program's test series this distance was constant 20.73 m, 68 ft) d_f is the distance from the camera to the fiducial marker (in this program's test series this distance was 17.98 m, 59 ft), α_2 is the angle from the horizontal to the fiducial marker, α_1 is the angle from the horizontal to the centerline of the fragment flight path.

Then the fragment velocity could be calculated using the following equation:

$$\text{Velocity} = V = \left[\frac{\Delta X}{N_f}\right] \cdot \left[V_f\right] \qquad (3)$$

where N_f is the number of frames over the measured displacement.

Also, a back up method was available for the cases when the timing lights would burn out or malfunction. The maximum speed of the Fastax camera can be

adjusted by regulating the supply voltage to the camera. If the supply is maintained constant, the camera's speed profile (frames per second versus time) is fairly reproducible. The camera speed versus the number of frames from the start (time zero)should be constant for each test where the supply voltage was the same .

In this program's test series, for all nine tests, the high speed cameras caught the event on film. Timings of the opening of the solenoid valve on the air gun's high pressure chamber and the starting of the cameras were correct since all events have been recorded. For this program some testing was extended into a fairly low velocity region 61 m/sec (200 ft/sec). However, note that a somehwat higher velocity of 82.9 to 88.1 m/sec (from 272 to 289 ft/sec) was attained. For the purpose of determining the accuracy of an analysis it is more important to know exactly the velocity of the impacting fragment rather than attaining a particular velocity.

Aiming Point Selection

It was felt that the collapse of the shell would send some of the molten explosive extruded out, and at the same time, increase the pressure on the fill thereby increasing the vulnerability of the munition. Due to this conclusion all of this program's aiming points were planned at the 10.8 cm (4.25 inches) from the top location. However, due to varying wind velocities, gun tube friction, and slight fragment instability, caused some impact points to be slightly off the desired impact point. Note at the start of each test series when large velocity and/or weight of fragment is changed, or when the air gun is put in use after winter storage, usually a few practice shots are required. Practice shots are necessary to check accurately the velocity of the fragment and on the impact location. Also, a practice shot verifies that the instrumentation as well as the air gun are functioning properly.

All actual hit locations for the tests are depicted in Table 3, and are noted on the field data sheets or can be observed from the still photos in the appendix of this report.

ANALYSIS

The ANSYS finite element computer program was used to determine the force-deflection, volume-deflection, and orifice area-deflection characteristics of the shell casing. The 4.2 inch H.E. mortar shell was selected for analysis because of its relatively uniform wall and its mid-range wall thickness. Making use of the shell symmetry, one quarter of the shell surface was modeled for finite element analysis as shown in Figures 15, 16, and 17. This approach also minimized the cost of the computer analysis. The deformed shape of the 4.2 inch mortar shell as determined by the computer analysis is depicted in Figure 18. Force-deflection characteristics were obtained by imposing three deflections and then computing the corresponding forces required to produce them. Deflections were imposed on the shell casing at nodes representing an area approximately equal to the contact area between the casing and the impacting concrete cylinder. The results of the finite element computer analyses are given in Tables 4, 5, and 6. Load deflections characteristics were determined for three pressures applied to the interior of the shell. Results are shown in Figure 19. Along with force-deflection characteristics of the shell casing, volume-deflection and orifice area-deflection characteristics were obtained from this analysis. These results are shown in Figures 20 and 21 respectively. It will be noted that both of these characteristics are independent of internal pressure. Also, at least for the selected shell casing, there was essentially no change in the orifice area with change in deflection, see Figure 21. A representative sample of the ANSYS computer input and output data and the analytical results are given in Appendix C of this report.

Next step was to determine the flow characteristics of the simulated explosive liquid through the filling orifice of the shell casing. The flow is dependent on the orifice area, the fluid pressure, viscosity, and the orifice coefficient. A single formula, see equation (1), relates the flow rate, Q to the internal pressure, p of the simulating liquid explosive and other parameters. The orifice coefficient was determined by the best fit of the analytical results to the experimental results which was taken as 0.64. Also the weight density of the liquid explosive was taken as approximately 85 lb/cu.ft. Table 7

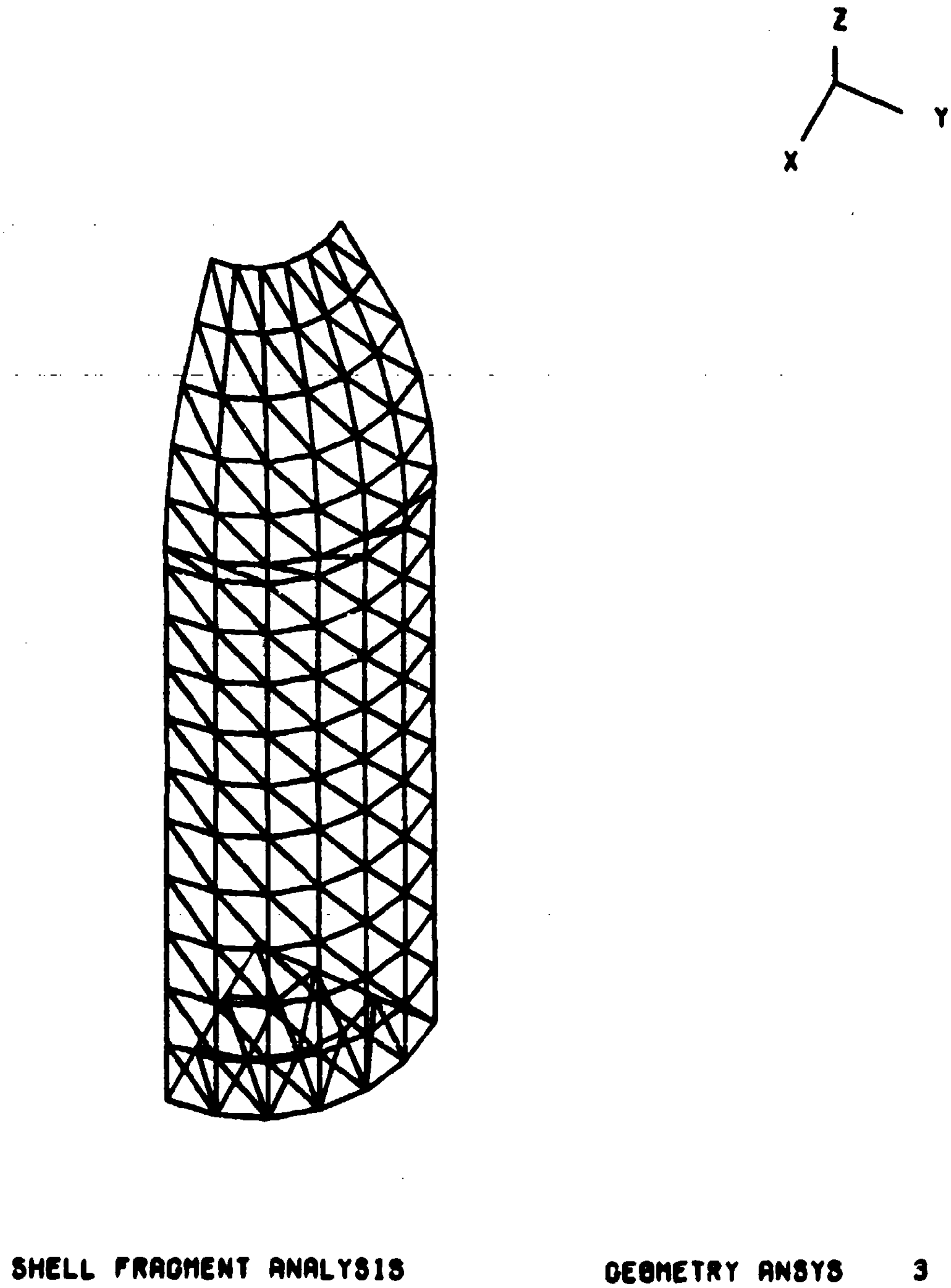

Figure 15 Finite Element Mesh of One Quarter of the Shell

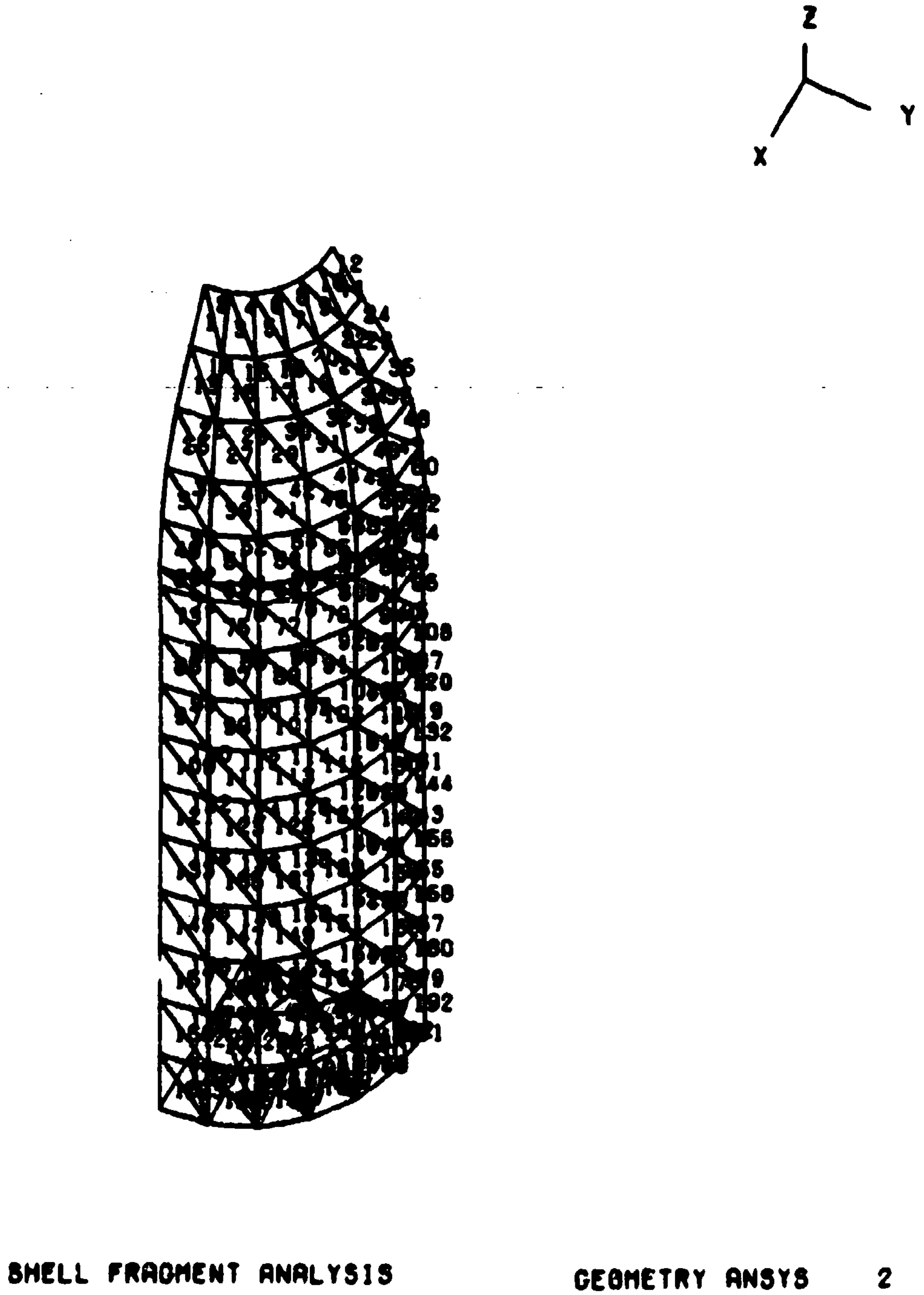

Figure 16 Finite Element Mesh with Elements Numbered

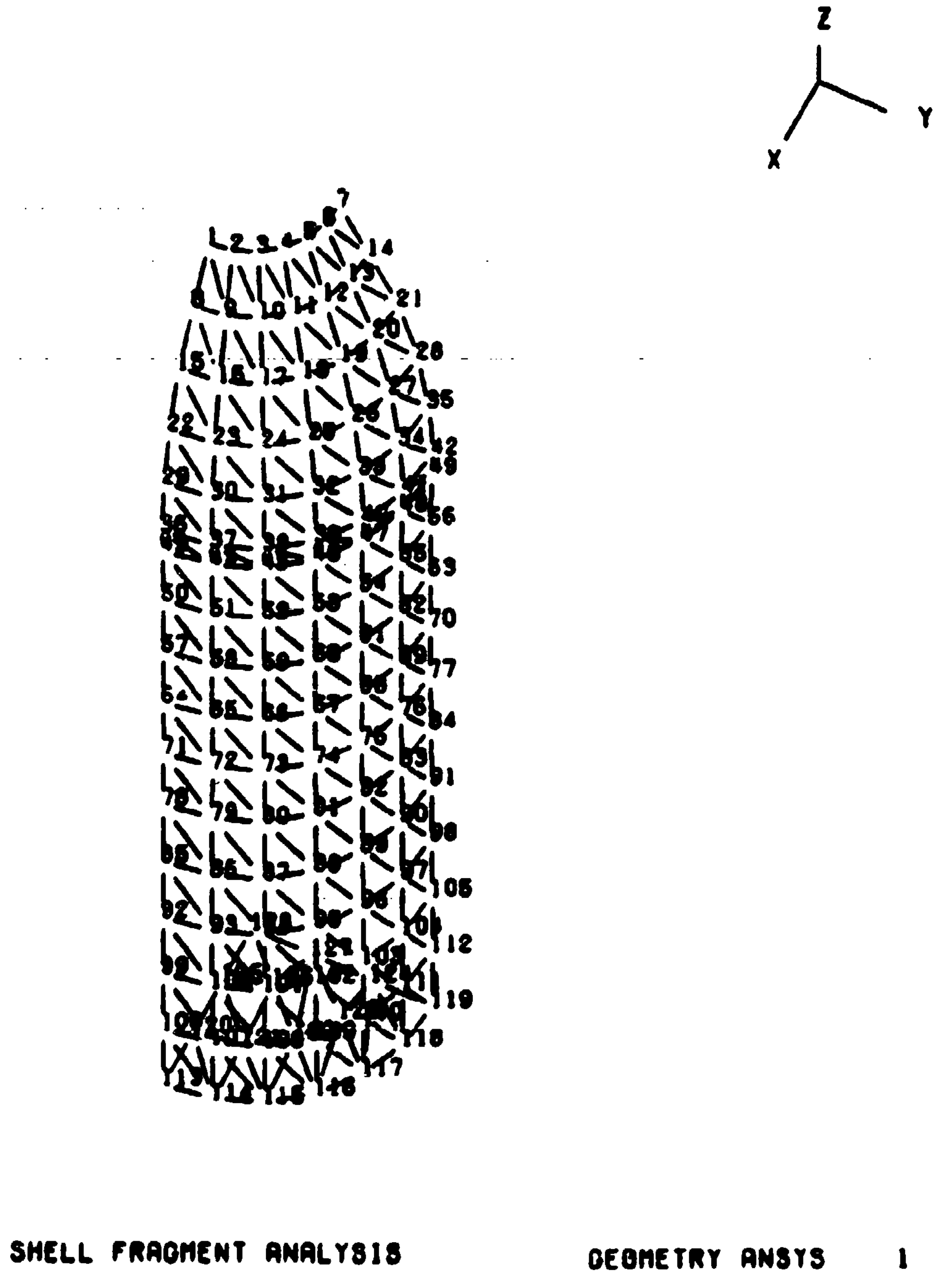

Figure 17 Finite Element Mesh with Nodes Numbered

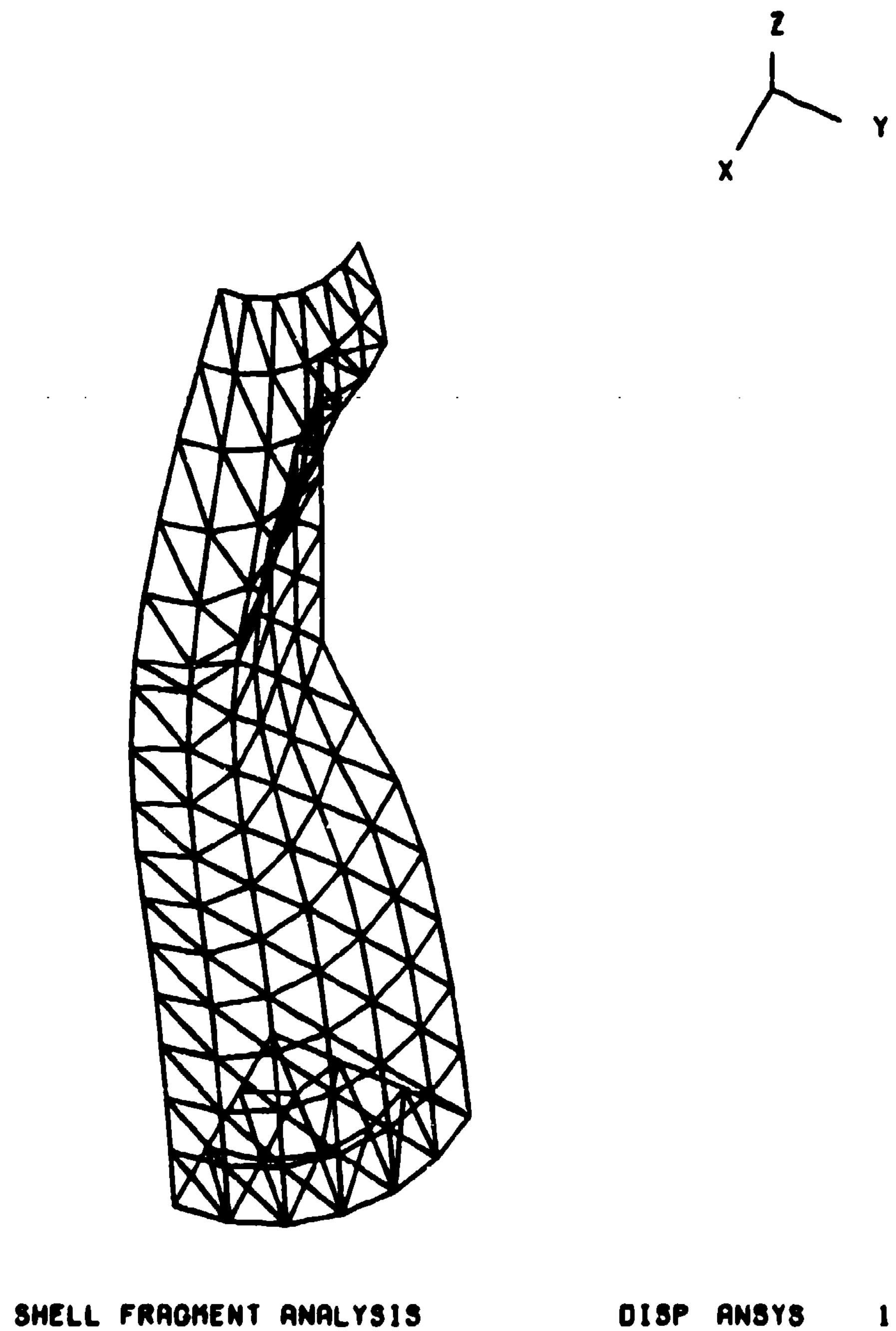

Figure 18 Finite Element Mesh After 1.5 Inches Deflection

TABLE 4. FORCE VS DEFLECTION FOR VARIOUS PRESSURES

Deflection (in.) \ Pressure (psi)	0	100	1000
	(lb)	(lb)	(lb)
0	0	0	0
0.5	55,000	58,000	83,000
1.0	250,000	280,000	330,000
1.5	230,000	262,000	310,000

TABLE 5. VOLUME VS DEFLECTION FOR VARIOUS PRESSURES

Deflection (in.) \ Pressure (psi)	0	100	1000
	($in.^3$)	($in.^3$)	($in.^3$)
0	175.0	175.0	175.0
0.5	170.2	170.2	170.2
1.0	157.5	157.5	157.5
1.5	133.2	133.2	133.2

TABLE 6. ORIFICE AREA VS DEFLECTION FOR VARIOUS PRESSURES

Deflection (in.) \ Pressure (psi)	0	100	1000
	($in.^2$)	($in.^2$)	($in.^2$)
0	2.886	2.836	2.886
0.5	2.887	2.887	2.887
1.0	2.889	2.889	2.889
1.5	2.895	2.895	2.895

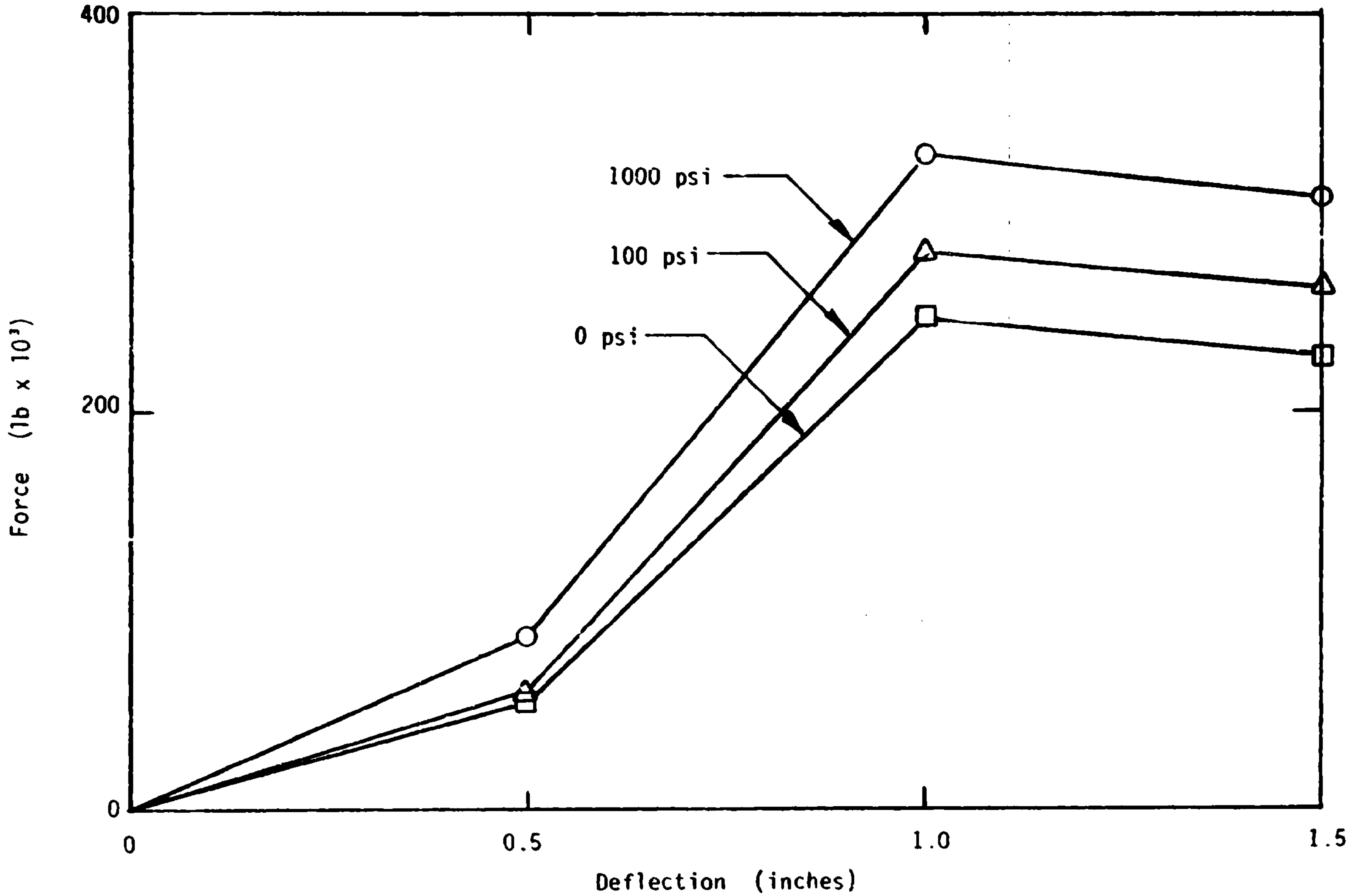

Figure 19 Force Versus Deflection Characteristics of the Shell Casing for Indicated Internal Pressures

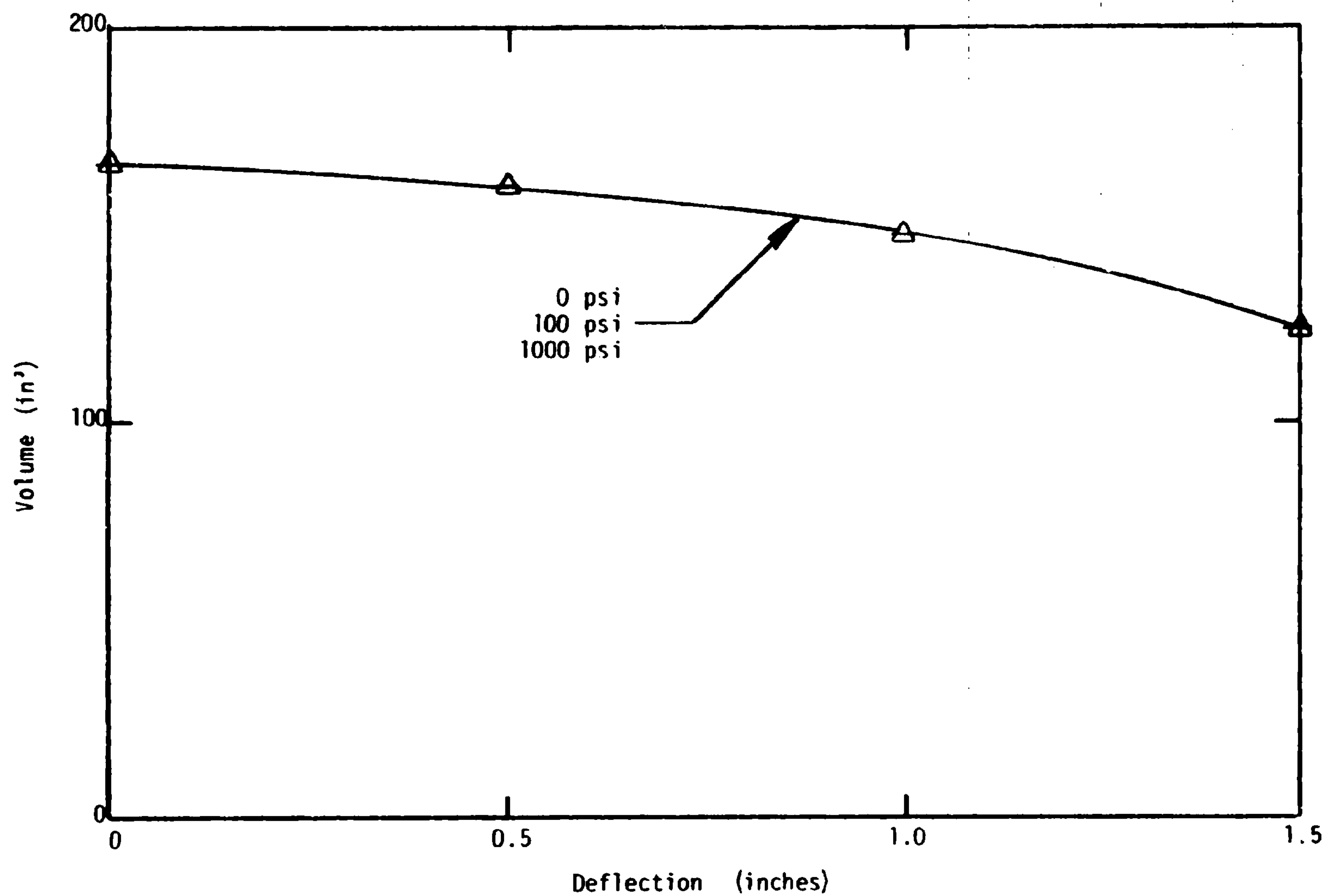

Figure 20 Volume Versus Deflection Characteristics of the Shell Casing

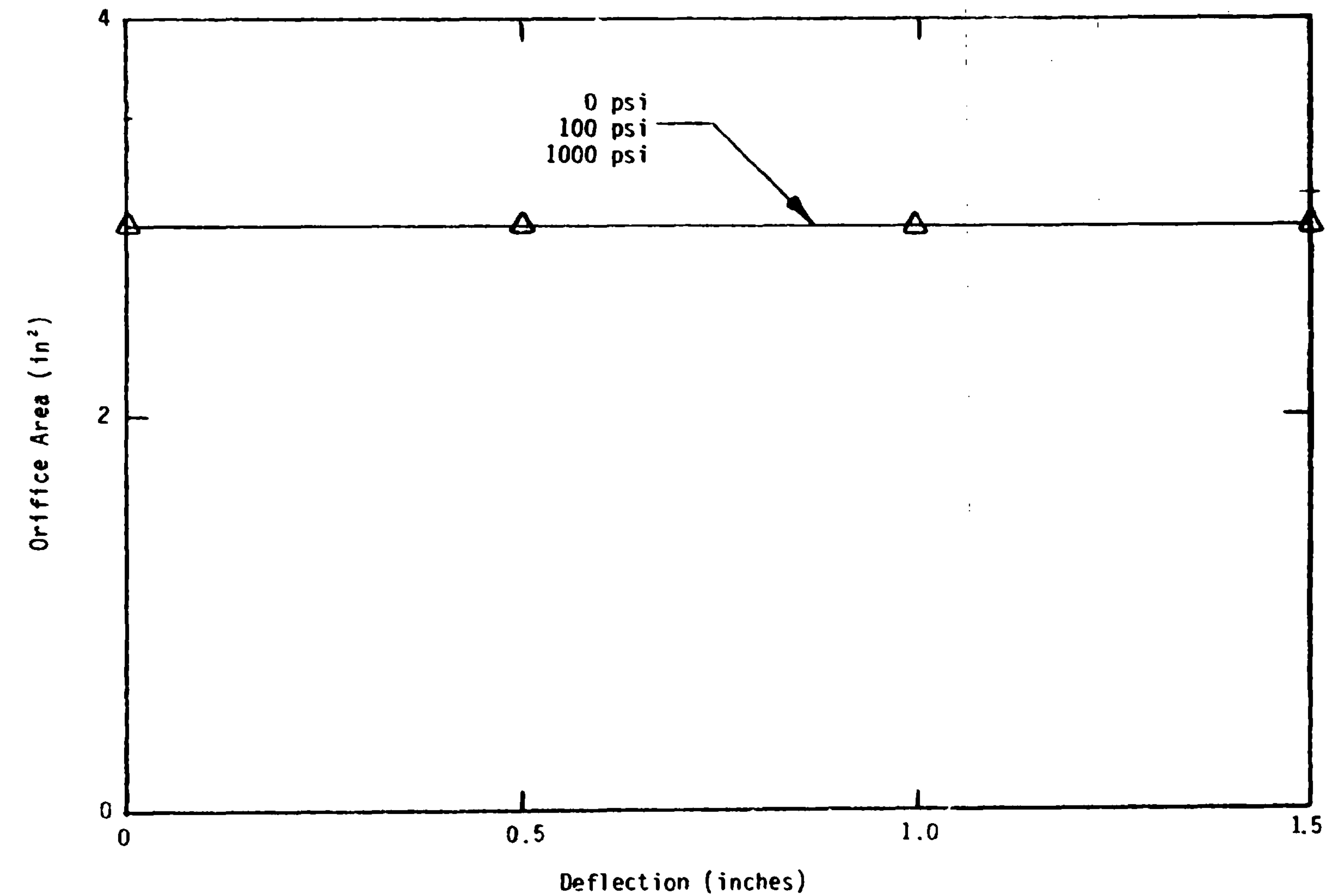

Figure 21 Orifice Area Versus Deflection Characteristics of the Shell Casing

TABLE 7. PRESSURE VS FLOW RATE FOR VARIOUS AREAS

Flow Rate (in.^{3}/sec) \ Area (in.^{2})	2.5	3.0	4.0
	(psi)	(psi)	(psi)
0	0	0	0
1000	41	29	16
2000	166	115	65
5000	1036	720	405
10,000	4145	2878	1619

presents the results of the flow analysis, and flow characteristics are shown in Figure 22 for the three selected orifice areas.

In the original analysis it was assumed that the simulated explosive liquid was incompressible. Analytic results using this assumption showed large rapid changes in the liquid pressure, suggesting compressibility. In the past it was observed that compression was approximately of the same order as the change in the casing volume due to impact deformation. The analysis was modified to take into account fluid compressibility. In the modified analysis the characteristics shown in Figure 22 are still used, however the corresponding internal pressure is modified on the basis of the bulk modulus of the liquid explosive, i.e.

$$\beta = \rho \frac{\Delta p}{\Delta \rho} \qquad (6)$$

where

β = bulk modulus, taken as 580,000 psi

ρ = weight density of the liquid

p = internal pressure

Figure 23 compares the original results assuming incompressible flow with the results assuming compressibility.

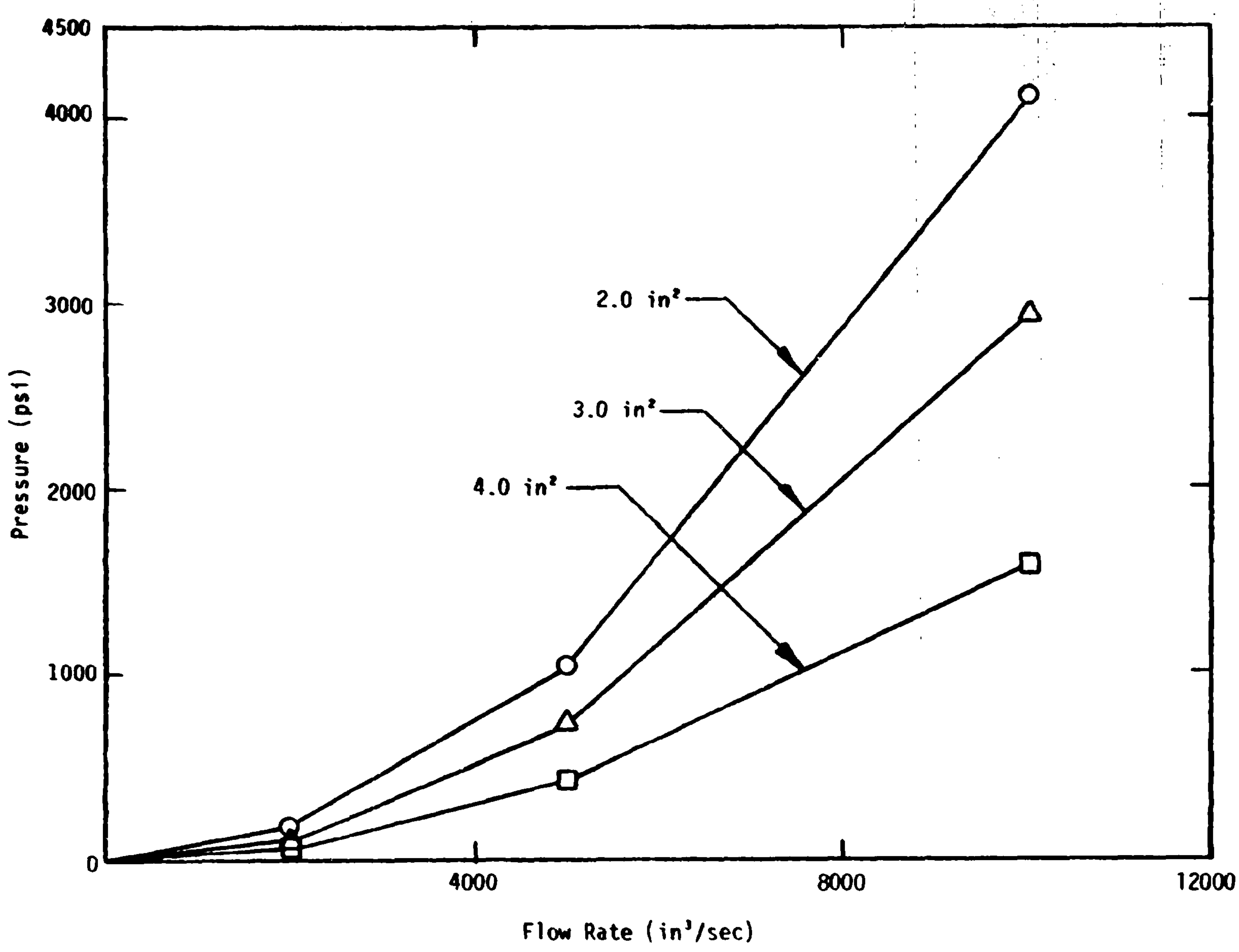

Figure 22 Pressure Versus Flow Rate for Three Orifice Areas

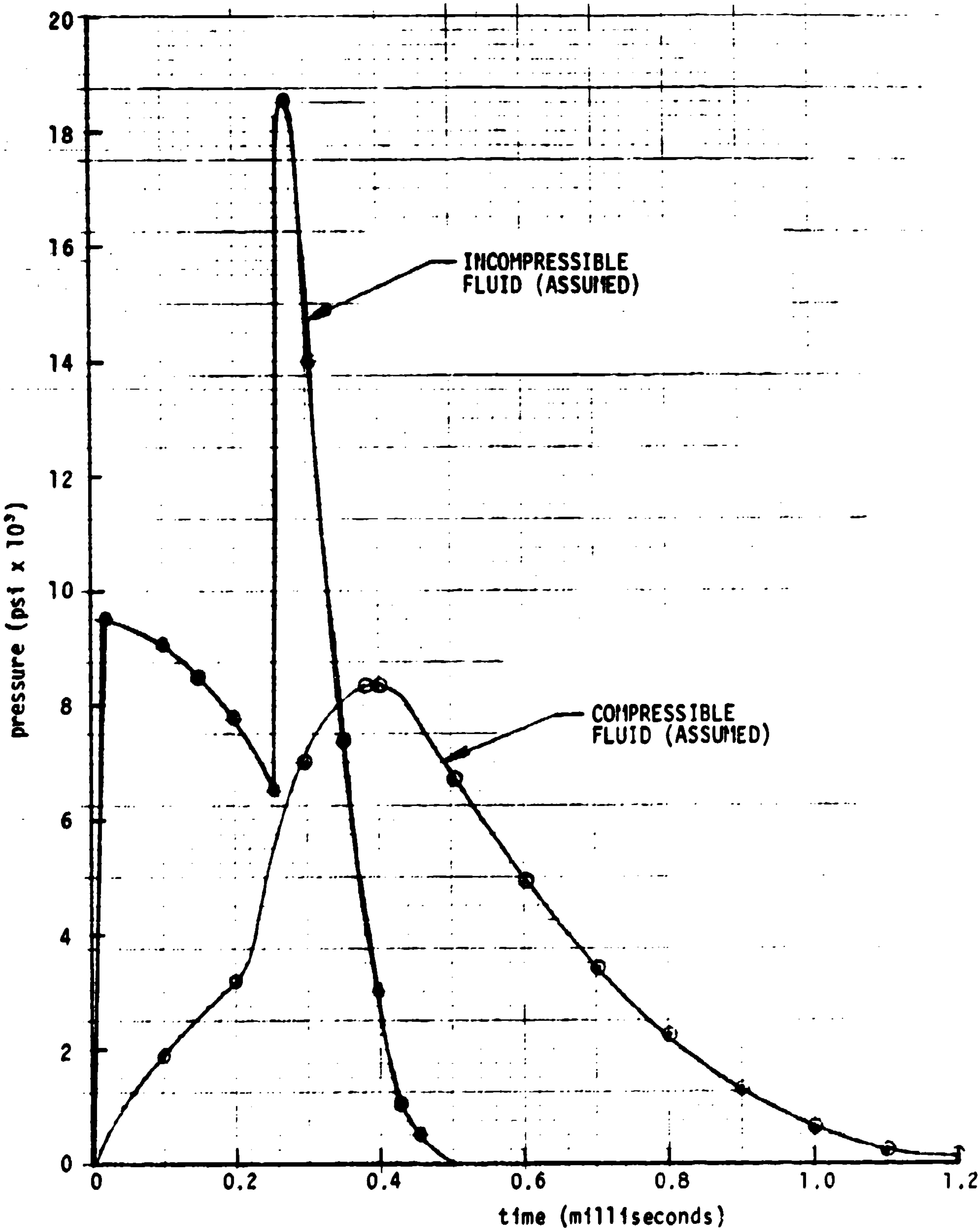

FIGURE 23 Comparison of Pressure Versus Time Analytical Results for Compressible and Incompressible Assumptions of Explosive Fluid

RESULTS

During this program an attempt was made to determine the mechanism controlling the impact sensitivity of molten explosive-filled shells when impacted by secondary fragments. To accomplish this, a simple analytic method was formulated for predicting pressure-time histories in shell casings filled with liquid explosives when impacted with secondary fragments. An analytic method was necessary to better understand the response of the shell to impact, as well as the shell casing's interaction with the explosive fill to cause it to develop sufficiently high pressures and temperatures that would lead to explosions. Also in order to determine the credibility and accuracy of the analysis, it was necessary to conduct instrumented experiments to measure the pressure-time history within the simulated liquid explosive when the shell containing it is impacted by a concrete fragment.

There are numerous primary initiation mechanisms when a container filled with explosive is impacted and collapsed by secondary concrete fragments. This program's effort was directed toward the most logical first step mechanism, namely the pressure rise of the explosive when the shell casing i- deformed. All the analytical and experimental effort was towards providing pressure-time data on the molten fill in a 4.2 inch H.E. mortar shell.

Four of the tests conducted during the experimental phase of this program provided useful pressure data for verification of the analytical calculations. There were experiments 3, 4, 6, and 7. The results of these experiments and their equivalent analytical simulations are summarized in Table 8. Figure 24, 25, 26, and 27 compare the pressure-time curves obtained from the experiment and from the analytical efforts during this project.

Incomplete experimental results were obtained from Experiment 3, therefore no conclusions can be drawn for this case. The results for Experiment 4 show good agreement between the analytical and the experimental results. The maximum pressures matched within 11 percent and the durations were within seven percent. The maximum deflections were not as close, 36 percent difference. The shapes of the experimental and the analytical curves show

TABLE 8 SUMMARY OF RESULTS

			Experimental			Analytical		
Exp. No.	Concrete Cylinder Weight	Concrete Cylinder Velocity	Maximum Pressure	Duration μ Sec	Maximum Deflection	Maximum Pressure	Duration μ Sec	Maximum Deflection
3	90.7 kg. (200 lb.)	85.0 m/sec (279 ft/sec)	--	--	3.61 cm (1.42 in.)	58,330 kPa (8460 psi)	550	2.31 cm (0.91 in.)
4	90.7 kg. (200 lb.)	82.9 m/sec (272 ft/sec)	45,230 kPa (6560 psi)	540	3.18 cm (1.25 in.)	40,472 kPa (5,870psi)	500	2.03 cm (0.80 in.)
6	90.7 kg. (200 lb.)	160.9 m/sec (528 ft/sec)	77,566 kPa (11,250 psi)	330	Bent 90°	194,225 kPa (28,170 psi)	600	3.20 cm (1.26 in.)
7	181.4 kg. (400 lb.)	67.1 m/sec (220 ft/sec)	54,400 kPa (7890 psi)	630	3.30 cm (1.30 in.)	45,505 kPa (6600 psi)	640	2.36 cm (0.93 in.)

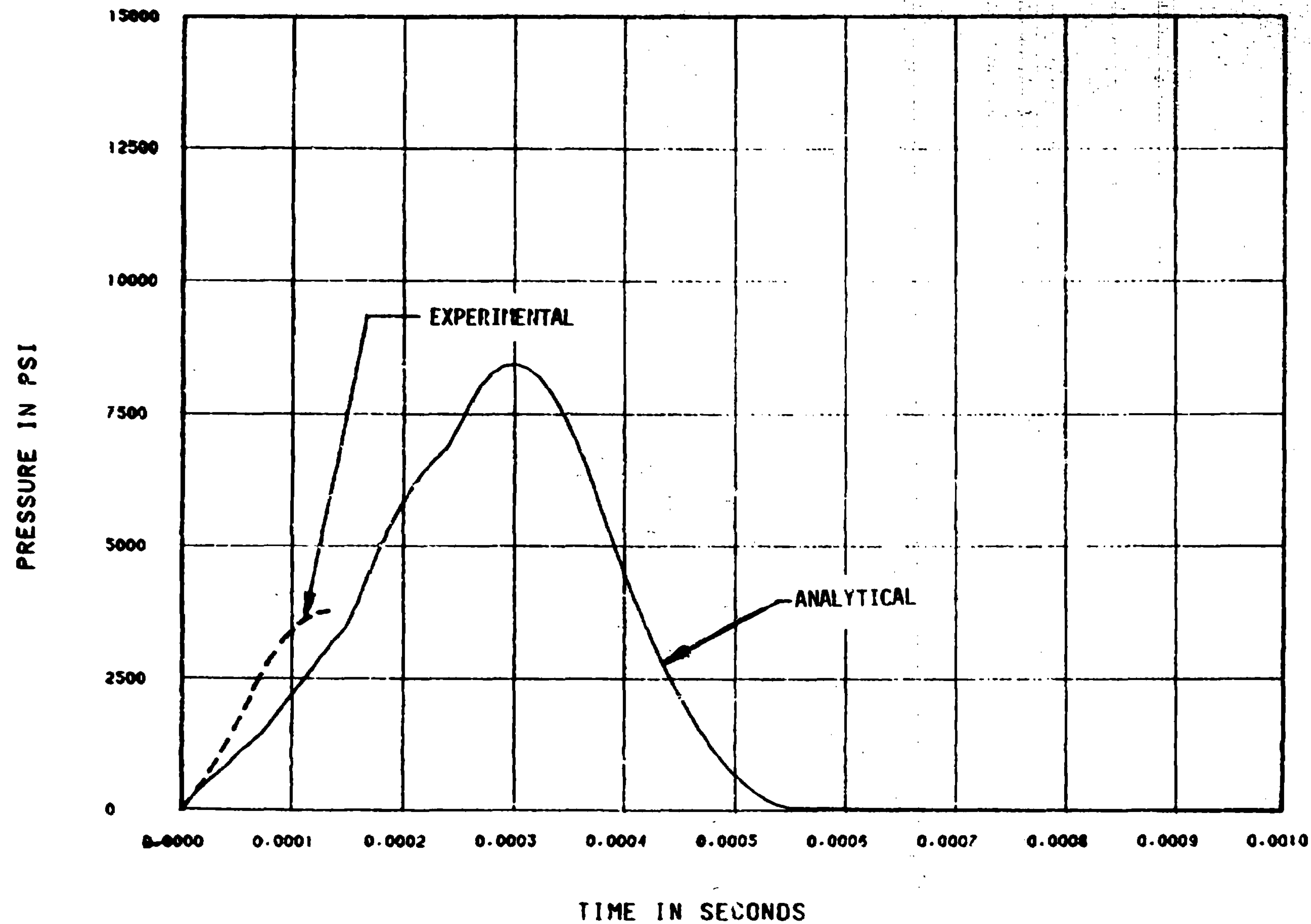

Figure 24 Pressure Versus Time Graph for Experiment 3
(Concrete Projectile 200 lb at 279 ft/sec Velocity)

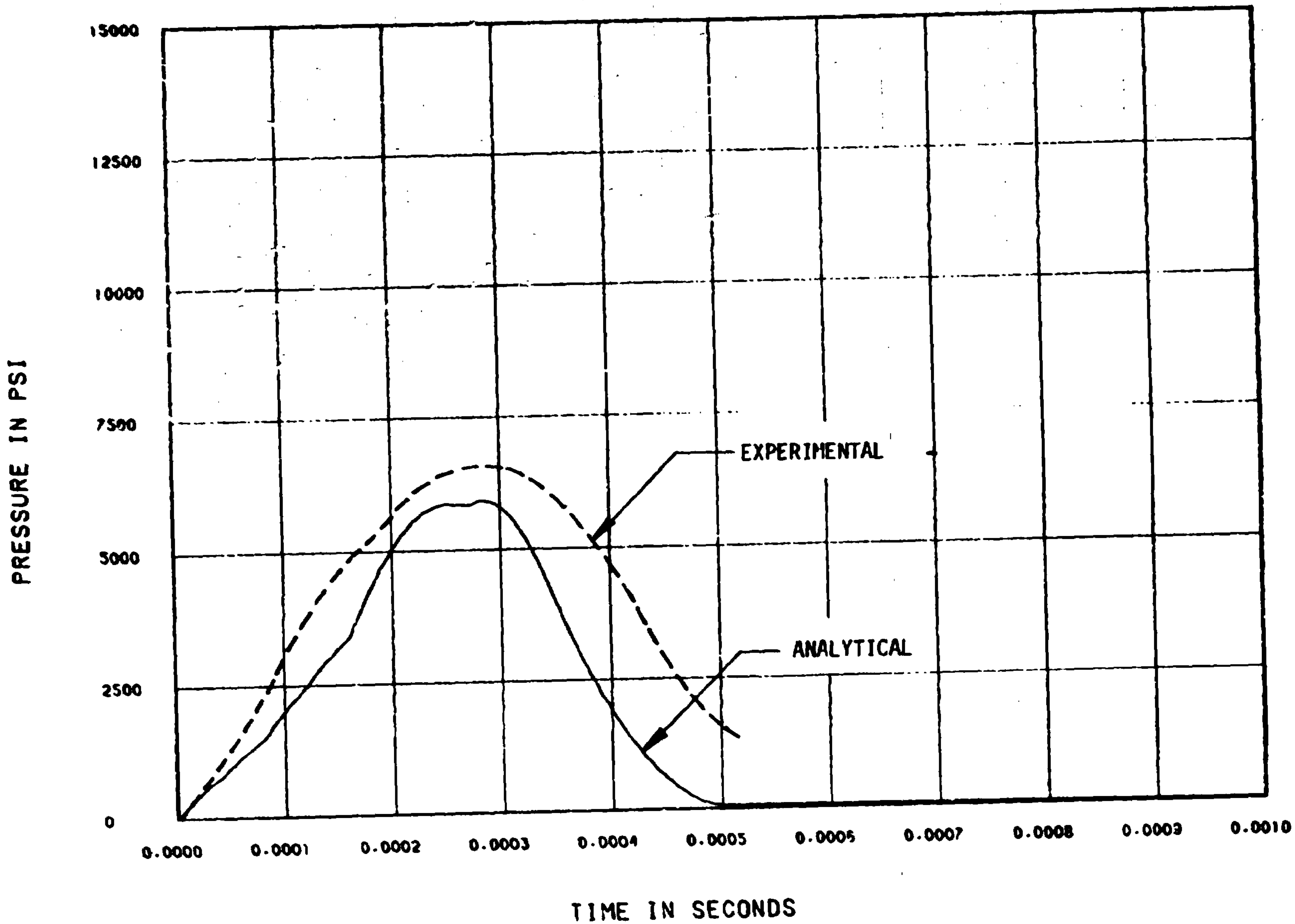

Figure 25 Pressure Versus Time Graph for Experiment 4
(Concrete Projectile 200 lb at 272 ft/sec Velocity)

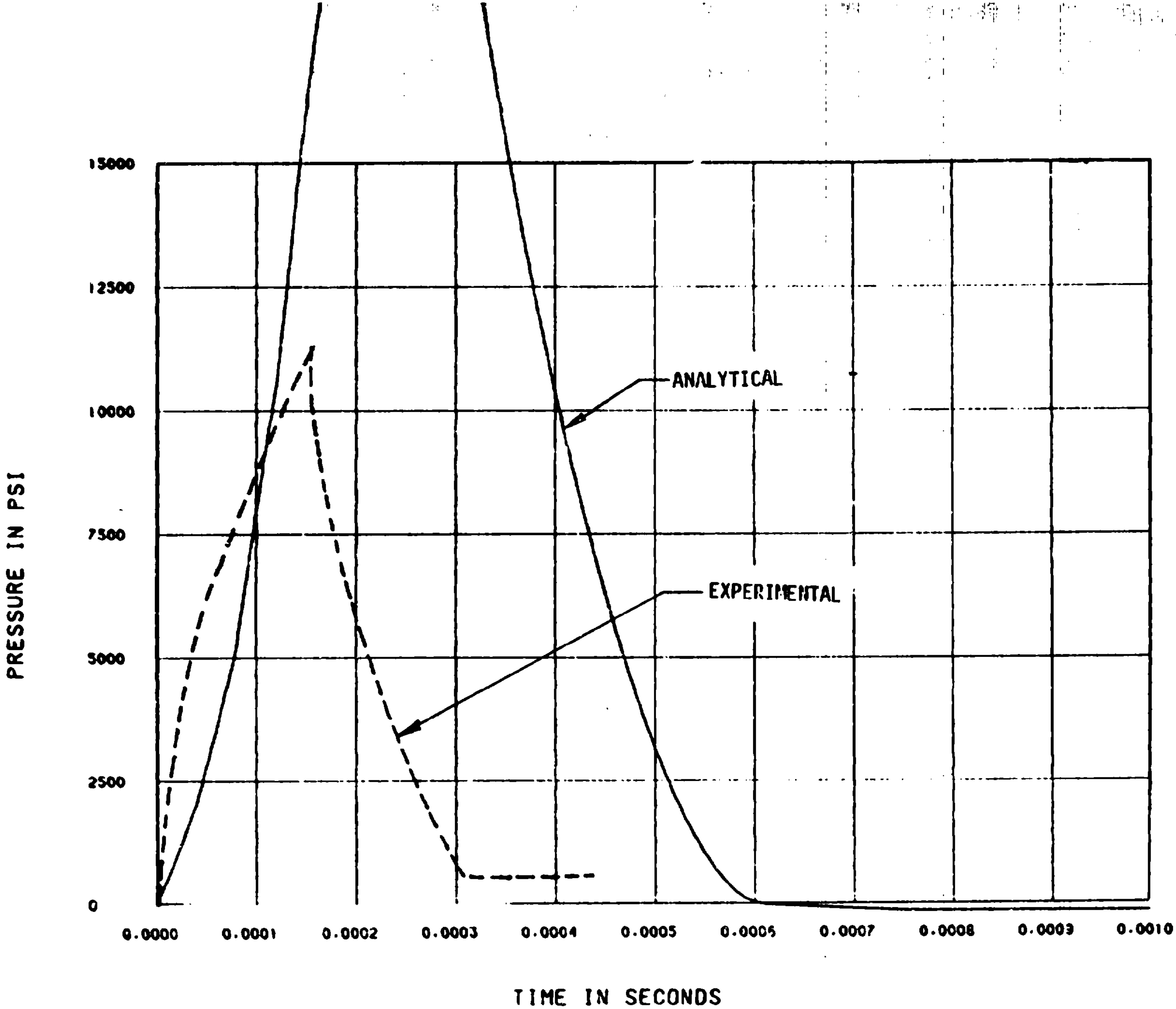

Figure 26 Pressure Versus Time Graph for Experiment 6
(Concrete Projectile 200 lb at 528 ft/sec Velocity)

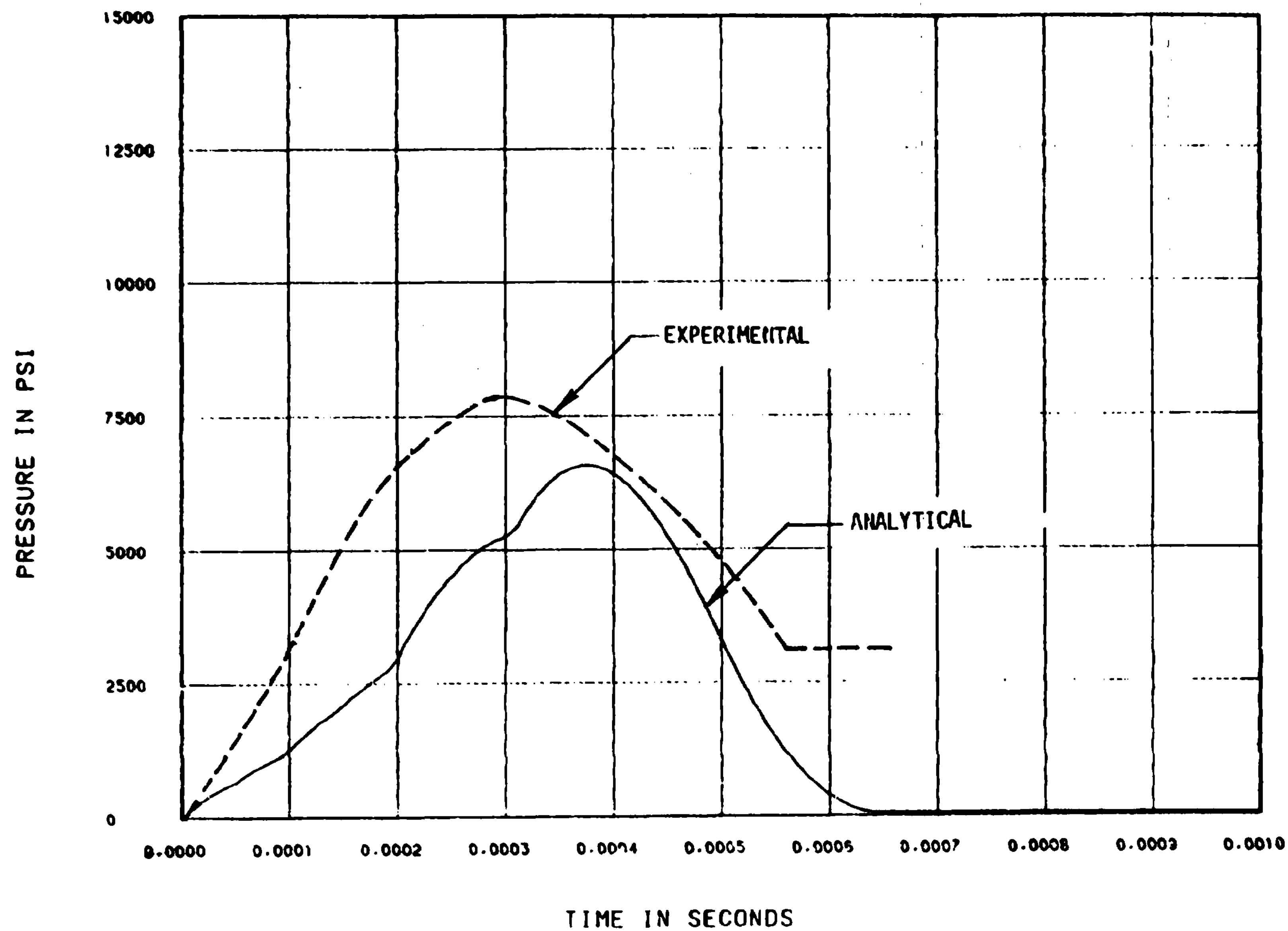

Figure 27 Pressure Versus Time Graph for Experiment 7
(Concrete Projectile 400 lb at 220 ft/sec Velocity)

good agreement. The shell's casing burst in Experiment 6 at about 11,250 psi. This is close to the expected burst presumed for this casing. Since complete failure of this casing was not considered in the analysis, a maximum pressure much higher than the burst pressure was predicted. The duration was also predicted to be much longer than the experimental results for the same reason. The results of Experiment 7 also show good agreement with very similar shaped pressure-time curves and differences of only 16 percent, 2 percent and 28 percent in the maximum pressure, duration and maximum deflection respectively.

In terms of the shape of the pressure-time history, duration and peak pressure, the comparison between experimental and analytic results appears to be favorable. These comparisons were only confirmed for one type of munition, and one primary initiation mechanism namely the pressure rise of its liquid explosive fill when impacted by a concrete fragment.

CONCLUSIONS

A finite element analytical method was formulated for predicting pressure-time histories in shell casing filled with liquid explosives when impacted with secondary fragments. Analytic results when compared to experimental results, gave a reasonable prediction of pressure versus time for a liquid explosive in a 4.2 inch H.E. mortar shell.

It was originally planned that the objective of this program was to determine the mechanism and/or mechanisms controlling the impact sensitivity of molten explosive filled shells when impacted by secondary fragments. There are numerous primary initiation mechanisms as well as geometric configurations in the Army arsenal of munitions that when shells filled with explosive are impacted and collapsed by secondary fragments could lead to explosions. However, due to limited time and funds on the program, the complex geometrics of the various shells produced for the Army, and the various mechanisms that can cause an explosion in an impacted/collapsed shell, the program was directed with mutual agreement of ARRADCOM towards one selected explosive filled shell and one specific primary mechanism, namely the pressure rise of the liquid during shell plastic deformation.

RECOMMENDATIONS

This program's analytic analysis and experimental test results produced reasonable predictions of pressure versus time for only one type of munition. The analytical procedure should be expanded to verify its applicability to a range of shells and explosive fills, with confirmations by sufficient instrumented explosive tests.

The computer code should be modified to handle cases of shell break-up. The analyses should include impact velocities at which initiation occurs. Finally, additional analysis will enhance the ability to determine whether the peak pressure in the liquid explosive, rate of pressure rise, temperature, etc., are parameters which individually or in combination will predict the onset of detonation in shells impacted by secondary fragments.

Specifically to expand this analytical procedure the following tasks/steps are recommended:

Task (a) Further modify the computer code. The modifications should include such factors as taking into account the rotation and tilt of the shell during impact, variations in the bulk modulus with temperature of the explosive, and shell break-up. Temperature should be computed at each time-step.

Task (b) Additional analytical predictions of pressure-time curves should be performed on past test parameters. Previous experimental programs were conducted to determine the sensitivity to impact by concrete fragments of the 4.2 inch mortar shell filled with Composition B and TNT. The analytical procedure as modified in Task (a) should be used to predict pressure versus time (P,τ) curves for as many as possible of these test cases so that one would have a large number of curves in order to distinguish between (P,τ) conditions for explosion and no reaction. Factors such as test velocity, weight of concrete projectile, and impact location on the shell should be identified in the analysis.

Task (c) Analyze the results and try to determine the nature of the pressure or temperature criteria that applies to detonation. The pressure versus time curves predicted in Task (b) along with the detonation results for

these tests should be analyzed to determine the pressure criteria that applies to detonations of shells. The criteria may be peak pressure alone; or temperature-time, or peak pressure and rate of rise of pressure; or peak pressure and total duration of the pulse; etc. The steps outlined in Task (a) and (b) above would provide this guidance.

Task (d) Run a study with molten explosives to verify the pressure criteria. The pressure criteria obtained in Task (c) should be verified by conducting tests with liquid explosive filled shell casings. The study should include tests in the predicted no detonation range, the detonation range, and the boundary line between detonation and no detonation. The tests should utilize pressure gages as in the current program as well as rapid response thermocouples placed in the molten explosive.

Task (e) The analytical procedure, which was applied to the 4.2 inch mortar shell, should be expanded to handle a full range of shells and explosives.

Task (f) The code should be fully documented and a users manual should be written which includes sample problems.

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APPENDIX A
FIELD DATA SHEETS

PROJECT J06523

CONTRACT DAAK10-80C-0160

FIELD DATA SHEET

SECONDARY FRAGMENT IMPACT TESTING

DESIRED FILM SPEED 3000 FRAMES/SEC

DATE: 11-30-'81

WEATHER CONDITIONS: 38°F CLOUDY

EXPLOSIVE DESCRIPTION: - NONE

EXPLOSIVE TEMP = ______ CASE TEMP = ______

AIR GUN PRESSURE: 280 PSI

DESIRED VELOCITY = 200 FT/SEC

ACTUAL VELOCITY = 278 FT/SEC

TEST NUMBER: 1 (PRACTICE)

FRAGMENT DESCRIPTION:

SOLID CONCRETE 19.75" DIA.

L/D = 2/1 DESIRED WT. = 200 LB.

ACTUAL WT. = 200 LB.

TARGET DESCRIPTION:

STEEL TUBE 4" O.D. × 15½" LONG FILLED WITH SAND

COMMENTS:

ONE OR TWO SHELLS USED?

TIMING:

Δt = 1.0 SEC

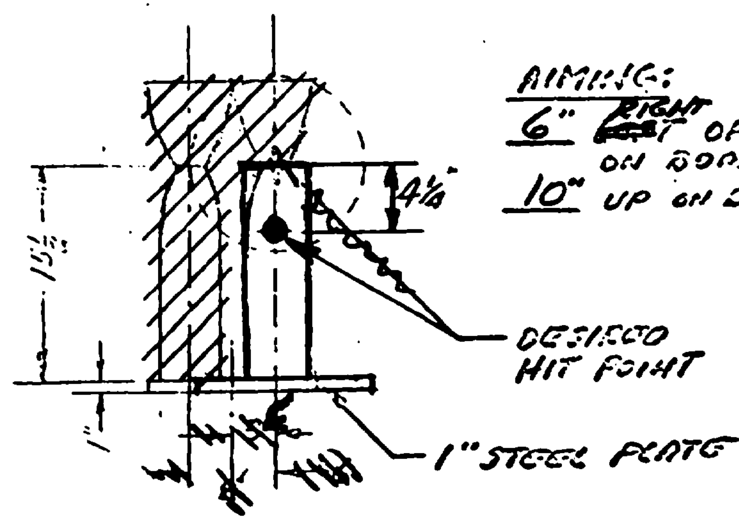
GUN = 0.5 SEC

CAMERA = 1.5 SEC

AIMING:

6" ~~LEFT~~ RIGHT OF ℄ ON BOARD

10" UP ON BOARD



RESULTS:

CONCRETE PROJECTILE MISSED TARGET - HIT TO THE RIGHT AND LOW

COMMENTS:

1. USE B&W HIGH SPEED FILM ONLY.
2. DEVELOP & CHECK VELOCITY
3. MAKE CHANGES IN
   a) PRESSURE
   b) AIM POINT
   c) TIMING
   IF NECESSARY

TEST ENGINEER: DALEY, AMOR, SWIDER

EXPERIMENT 1

PROJECT J06523
CONTRACT
DAAK10-80C-0060

FIELD DATA SHEET
SECONDARY FRAGMENT IMPACT TESTING

DESIRED FILM SPEED 3000 FRAMES/SEC.

DATE: 12-1-'81
WEATHER CONDITIONS: CLOUDY

EXPLOSIVE DESCRIPTION: MOLTEN- ______
EXPLOSIVE TEMP. = ______ CASE TEMP. = ______
AIR GUN PRESSURE: 290 PSI
DESIRED VELOCITY = 200 FT/SEC
ACTUAL VELOCITY = 289 FT/SEC

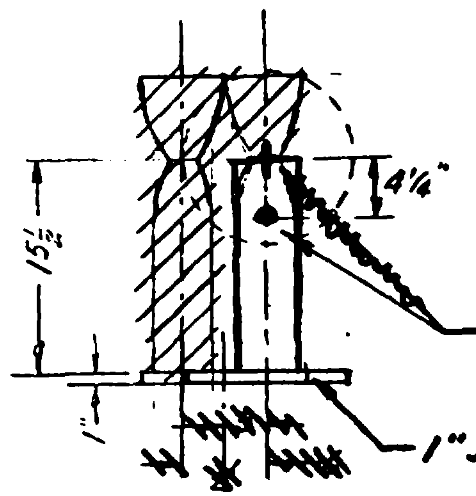
TEST NUMBER: 2 (PRACTICE)

FRAGMENT DESCRIPTION:
SOLID CONCRETE 10.75" DIA.
L/D = 2/1 DESIRED WT. = 200 LB
ACTUAL WT. = 200 LB
TARGET DESCRIPTION:
STEEL TUBE 4" O.D. X 15½" LONG
FILLED WITH SAND

COMMENTS:
ONE OR TWO SHELLS USED?

TIMING:
Δt = 0.5 SEC
GUN = 0.5 SEC
CAMERA = 1.0 SEC

AIMING:
4" LEFT OF ℄ ON BOARD
18" UP ON BOARD



RESULTS:
CONCRETE PROJECTILE HIT AT PROPER HEIGHT BUT A LITTLE TO THE LEFT
(SEE STILL PHOTO)

COMMENTS
1. USE B&W HIGH SPEED FILM ONLY
2. DEVELOP & CHECK VELOCITY
3. MAKE CHANGES IN
   a) PRESSURE
   b) AIM POINT
   c) TIMING
   IF NECESSARY

TEST ENGINEER: DALEY, AMOR

EXPERIMENT 2

PROJECT J06523
CONTRACT
DAAK10-80C-0160

FIELD DATA SHEET

SECONDARY FRAGMENT IMPACT TESTING

DESIRED FILM SPEED 3000 FRAMES/SEC.

DATE: 12-1-'81
WEATHER CONDITIONS: 48°F CLOUDY

EXPLOSIVE DESCRIPTION: MOLTEN-
EXPLOSIVE TEMP. = CASE TEMP. =
AIR GUN PRESSURE: 280 PSI
DESIRED VELOCITY = 200 FT/SEC
ACTUAL VELOCITY = 279 FT/SEC

TEST NUMBER: 3

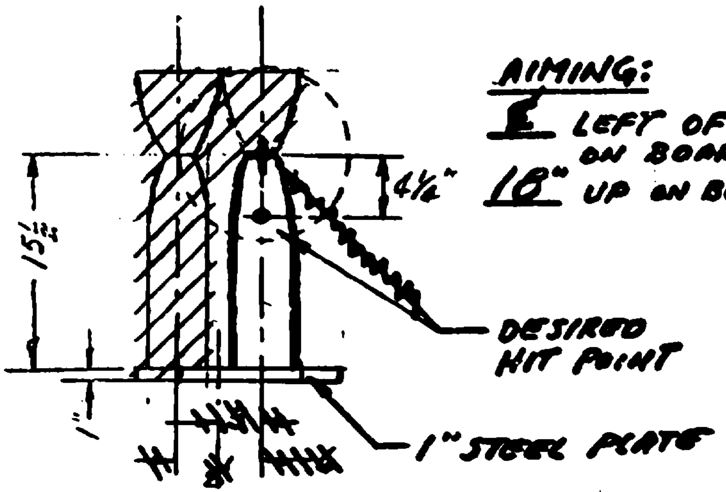
FRAGMENT DESCRIPTION:
SOLID CONCRETE 10.75" DIA.
L/D = 2/1 DESIRED WT. = 200 LB
ACTUAL WT. = 200 LB

TARGET DESCRIPTION:
4.2 INCH SHELL FILLED WITH GLYCERIN & WATER AT AMBIENT TEMPERATURE

COMMENTS:
ONE OR TWO SHELLS USED?

TIMING:
Δt = 0.5 SEC
GUN = 0.5 SEC
CAMERA = 1.0 SEC

AIMING:
$\mathbf{C}$ LEFT OF $\mathbf{C}$ ON BOARD
18" UP ON BOARD



RESULTS:
CONCRETE PROJECTILE HIT AT DESIRED LOCATION (SEE STILL PHOTO)

COMMENTS
4.2 INCH SHELL SCRIBED WITH 1" GRID USED (OLD)
USED B&W AND COLOR HIGH SPEED FILM

BY WT. 86.5% GLYCERIN
BY WT. 13.5% WATER
(300 CENTIPOISE)

NO PEAK PRESSURE – RISE IN PRESSURE = 5099 PSI IN 123 μSEC
DEFLECTION ~ 1.48" INCHES
TEST ENGINEER: DALEY, AMOR

EXPERIMENT 3

PROJECT J06523
CONTRACT
DAAK10-80C-0160

FIELD DATA SHEET

SECONDARY FRAGMENT IMPACT TESTING

DESIRED FILM SPEED 5000 FRAMES/SEC.

DATE: 12-2-'81
WEATHER CONDITIONS: 39°F CLOUDY

EXPLOSIVE DESCRIPTION: MOLTEN-
EXPLOSIVE TEMP. = ____ CASE TEMP. = ____
AIR GUN PRESSURE: 280 PSI
DESIRED VELOCITY = 200 FT/SEC
ACTUAL VELOCITY = 272 FT/SEC

TEST NUMBER: 4

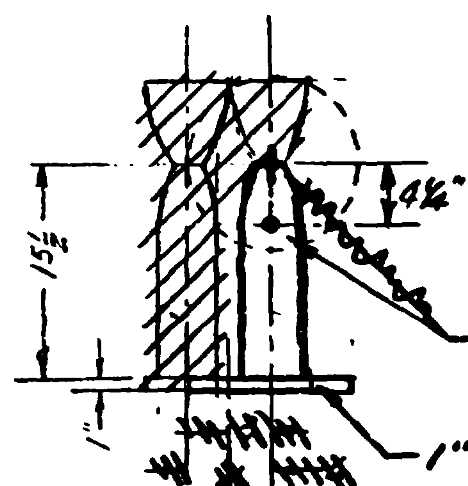
FRAGMENT DESCRIPTION:
SOLID CONCRETE 10.75" DIA.
L/D = 2/1 DESIRED WT. = 200 LB.
ACTUAL WT. = 200 LB.

TARGET DESCRIPTION:
4.2 INCH SHELL FILLED WITH GLYCERIN & WATER AT AMBIENT TEMPERATURE

COMMENTS:
ONE OR TWO SHELLS USED ?

TIMING:
Δt = 0.5 SEC
GUN = 0.5 SEC
CAMERA = 1.0 SEC

AIMING:
1 ~~LEFT~~ RIGHT OF ℄ ON BOARD
16" UP ON BOARD



RESULTS:
CONCRETE PROJECTILE HIT AT DESIRED LOCATION (SEE STILL PHOTO)

COMMENTS
4.2 INCH SHELL SCRIBED WITH 1" GRID USED (OLD)
USED B&W AND COLOR HIGH SPEED FILM
BY WT. 83.5% GLYCERIN
BY WT. 16.5% WATER
PEAK PRESSURE 6805 PSI IN 264 μSEC
DURATION 645 μSEC
DEFLECTION ~ 1.2 TO 1.3 INCHES

TEST ENGINEER: DALEY, AMOR

EXPERIMENT 4

PROJECT NO. J06523 **FIELD DATA SHEET** DESIRED FILM SPEED 3000 FRAMES/SEC

CONTRACT DAAK10-80C-0160

SECONDARY FRAGMENT IMPACT TESTING

DATE: 12-3-'81

WEATHER CONDITIONS: CLOUDY

EXPLOSIVE DESCRIPTION: MOLTEN-

EXPLOSIVE TEMP. = ____ CASE TEMP. = ____

AIR GUN PRESSURE: 1200 PSI

DESIRED VELOCITY = 500 FT/SEC

ACTUAL VELOCITY = 432 FT/SEC

TEST NUMBER: 5 (PRACTICE)

FRAGMENT DESCRIPTION:

SOLID CONCRETE 10.75" DIA.

L/D = 2/1 DESIRED WT. = 200 LB

ACTUAL WT. = 200 LB

TARGET DESCRIPTION:

STEEL TUBE 4" O.D. x 15½" LONG FILLED WITH SAND

COMMENTS:

ONE OR TWO SHELLS USED?

TIMING:

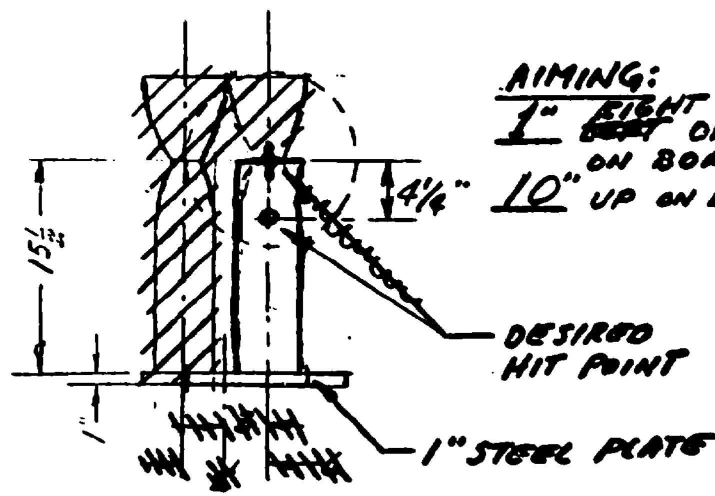
Δt = 0.2 SEC

GUN = 0.5 SEC

CAMERA = 0.7 SEC

RESULTS:

CONCRETE PROJECTILE HIT TARGET AT DESIRED LOCATION



AIMING:

1" ~~LEFT~~ RIGHT OF ℄ ON BOARD

10" UP ON BOARD

COMMENTS

1. USE B&W HIGH SPEED FILM ONLY
2. DEVELOP & CHECK VELOCITY
3. MAKE CHANGES IN
   a) PRESSURE
   b) AIM POINT
   c) TIMING

   IF NECESSARY

TEST ENGINEER: DALEY, AMOR

EXPERIMENT 5

PROJECT J06523 — FIELD DATA SHEET

CONTRACT
DAAK10-80C-0160

DESIRED FILM SPEED 5000 FRAMES/SEC

SECONDARY FRAGMENT IMPACT TESTING

DATE: 12-4-81

WEATHER CONDITIONS: 44°F CLOUDY

EXPLOSIVE DESCRIPTION: MOLTEN-______

EXPLOSIVE TEMP. = ______ CASE TEMP. = ______

AIR GUN PRESSURE: 1200 PSI

DESIRED VELOCITY = 500 FT/SEC

ACTUAL VELOCITY = 528 FT/SEC

TEST NUMBER: 6

FRAGMENT DESCRIPTION:

SOLID CONCRETE 10.75" DIA.

L/D = 2/1 DESIRED WT. = 200 LB.

ACTUAL WT. = 200 LB.

TARGET DESCRIPTION:

4.2 INCH SHELL FILLED WITH GLYCERIN & WATER AT AMBIENT TEMPERATURE

COMMENTS:

ONE OR TWO SHELLS USED?

TIMING:

Δt = −0.3 SEC

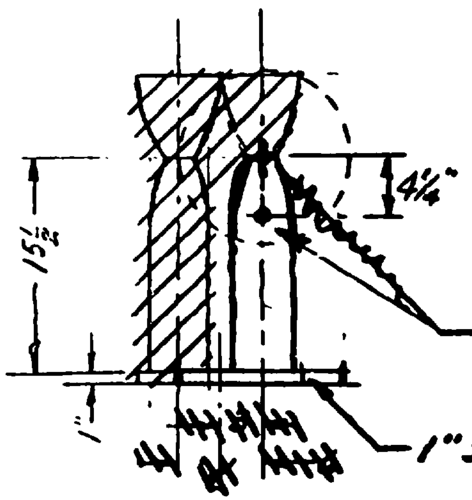
GUN = 0.8 SEC

CAMERA = 0.5 SEC

AIMING:

1" ~~LEFT~~ RIGHT OF ℄ ON BOARD

10" UP ON BOARD



RESULTS:

CONCRETE PROJECTILE HIT AT DESIRED LOCATION

(SEE STILL PHOTO)

COMMENTS

4.2 INCH SHELL SCRIBED WITH 1" GRID USED (OLD)

USED B&W AND COLOR HIGH SPEED FILM

BY WT. 85% GLYCERIN

BY WT. 15% WATER

PEAK PRESSURE 11,307 PSI IN 159 μSEC

DURATION 304 μSEC AT LEAST

DAMAGED PRESSURE GAGE

DEFLECTION BENT 90° AND TORN APART

TEST ENGINEER: DALEY, AMOR

EXPERIMENT 6

PROJECT J06523
CONTRACT
DAAK10-80C-0160

FIELD DATA SHEET

SECONDARY FRAGMENT IMPACT TESTING

DESIRED FILM SPEED 3000 FRAMES/SEC

DATE: 12-9-'81

WEATHER CONDITIONS: 30°F INTER. SNOW & BROKEN CLOUDS

EXPLOSIVE DESCRIPTION: MOLTEN-

EXPLOSIVE TEMP. = ____ CASE TEMP. = ____

AIR GUN PRESSURE: 350 PSI

DESIRED VELOCITY = 200 FT/SEC
ACTUAL VELOCITY = 220 FT/SEC

TEST NUMBER: 7

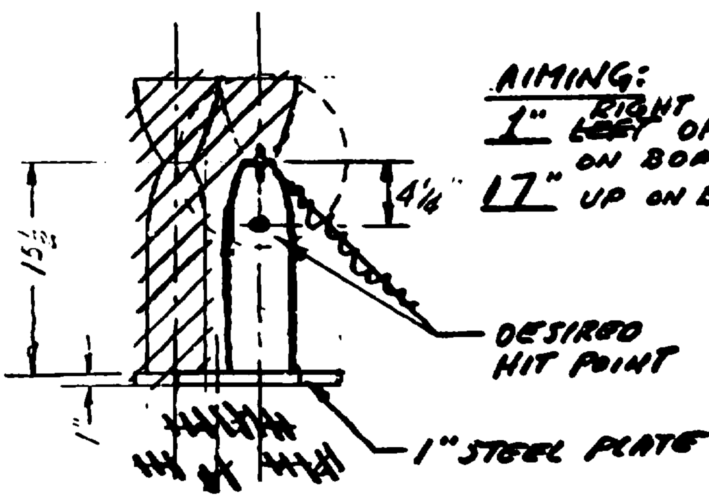
FRAGMENT DESCRIPTION:
SOLID CONCRETE 10.75" DIA.
L/D = 4/1 DESIRED WT. = 400 LB
ACTUAL WT. = 400 LB

TARGET DESCRIPTION:
4.2 INCH SHELL FILLED WITH GLYCERIN & WATER AT AMBIENT TEMPERATURE

COMMENTS:
ONE OR TWO SHELLS USED?

TIMING:
Δt = 0.3 SEC
GUN = 0.5 SEC
CAMERA = 0.8 SEC

AIMING:
1" ~~LEFT~~ RIGHT OF ℄ ON BOARD
17" UP ON BOARD



RESULTS:
CONCRETE PROJECTILE HIT AT DESIRED LOCATION
(SEE STILL PHOTO)

COMMENTS
4.2 INCH SHELL SCRIBED WITH 1" GRID USED (OLD)
USED B&W AND COLOR HIGH SPEED FILM
BY WT. 80% GLYCERIN
BY WT. 20% WATER
PEAK PRESSURE 8336 PSI IN 326 μSEC
DURATION 592 μSEC AT LEAST
DEFLECTION ~ 1.2 TO 1.4 INCHES
WT OF EMPTY SHELL 15 LB
WT. OF SHELL & GLYCERIN 21.5 LB

TEST ENGINEER: DALEY, AMOR

EXPERIMENT 7

PROJECT J06523
CONTRACT
DAAK10-80C-0160

FIELD DATA SHEET

DESIRED FILM SPEED 3000 FRAMES/SEC

SECONDARY FRAGMENT IMPACT TESTING

DATE: 12-10-'81
WEATHER CONDITIONS: 32°F OVERCAST & SNOWING

EXPLOSIVE DESCRIPTION: MOLTEN-______
EXPLOSIVE TEMP. =______ CASE TEMP. =______
AIR GUN PRESSURE: 280 PSI
DESIRED VELOCITY = 200 FT/SEC
ACTUAL VELOCITY = 289 FT/SEC

TEST NUMBER: 8

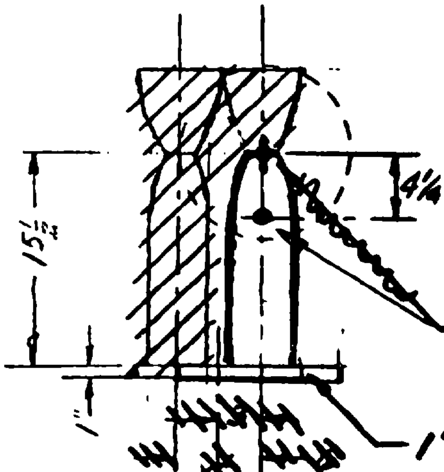
FRAGMENT DESCRIPTION:
SOLID CONCRETE 10.75" DIA.
L/D = 2/1 DESIRED WT. = 200 LB
ACTUAL WT. = 200 LB

TARGET DESCRIPTION:
4.2 INCH SHELL FILLED WITH GLYCERIN & WATER AT AMBIENT TEMPERATURE

COMMENTS:
ONE OR TWO SHELLS USED?

TIMING:
Δt = 0.4 SEC
GUN = 0.5 SEC
CAMERA = 0.9 SEC

AIMING:
1" FRONT OF ℄ ON BOARD
14" UP ON BOARD



RESULTS:
CONCRETE PROJECTILE HIT AT DESIRED LOCATION - A LITTLE LOW
SHELL BROKEN INTO PIECES
(SEE STILL PHOTO)

COMMENTS:
4.2 INCH SHELL SCRIBED WITH 1" GRID USED (NEW)
USED B&W AND COLOR HIGH SPEED FILM
BY WT. 83% GLYCERIN
BY WT. 17% WATER

NO PRESSURE GAGE IN FLUID

DEFLECTION - SHELL IN PIECES

WT. OF EMPTY SHELL 14 LB.
WT OF SHELL & GLYCERIN 18.5 LB.

TEST ENGINEER: DALEY, AMOR

EXPERIMENT 8

PROJECT J06523
CONTRACT
DAAK10-80C-0160

FIELD DATA SHEET

SECONDARY FRAGMENT IMPACT TESTING

DESIRED FILM SPEED 3000 FRAMES/SEC

DATE: 12-11-'81

WEATHER CONDITIONS: 36°F OVERCAST

EXPLOSIVE DESCRIPTION: MOLTEN-

EXPLOSIVE TEMP. = ______ CASE TEMP. = ______

AIR GUN PRESSURE: 280 PSI

DESIRED VELOCITY = 200 FT/SEC

ACTUAL VELOCITY = 281 FT/SEC

TEST NUMBER: 9

FRAGMENT DESCRIPTION:

SOLID CONCRETE 10.75" DIA.

L/D = 2/1 DESIRED WT. = 200 LB.

ACTUAL WT. = 200 LB.

TARGET DESCRIPTION:

4.2 INCH SHELL FILLED WITH TNT (JUST FILLED)

COMMENTS:

ONE OR TWO SHELLS USED?

TIMING:

Δt = 0.4 SEC

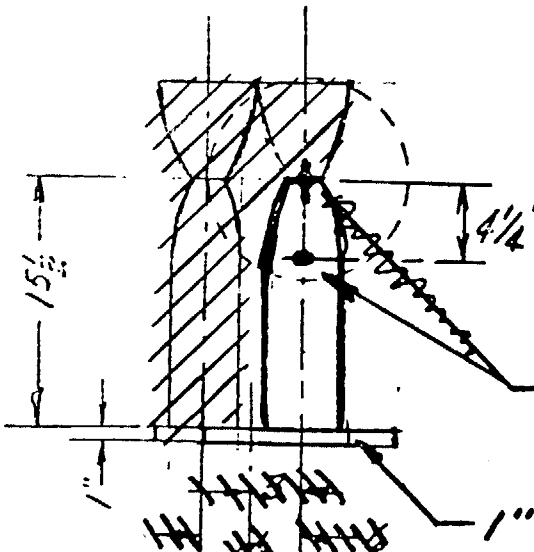
GUN = 0.5 SEC

CAMERA = 0.9 SEC

AIMING:

1" ~~LEFT~~ RIGHT OF ℄ ON BOARD

14" UP ON BOARD



RESULTS:

CONCRETE PROJECTILE HIT AT DESIRED LOCATION - BASE OF SHELL MISSING - SOME SOLIDIFIED TNT LEFT IN NOSE OF SHELL (SEE STILL PHOTO) LITTLE LOW

COMMENTS

4.2 INCH SHELL SCRIBED WITH 1" GRID USED (NEW)

NO PRESSURE GAGE IN TNT

DEFLECTION ~ 0.8 TO 0.9 INCHES (BASE MISSING)

TNT TEMPERATURE @ 185°F

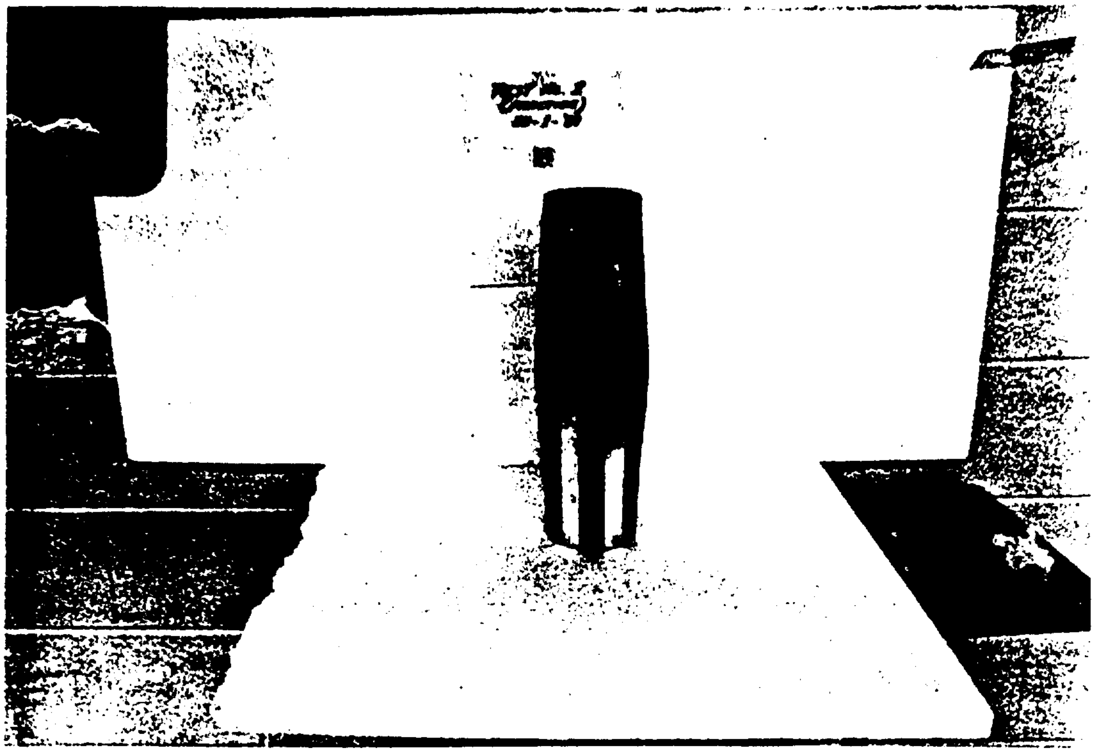
WT. OF EMPTY SHELL 14 LB.

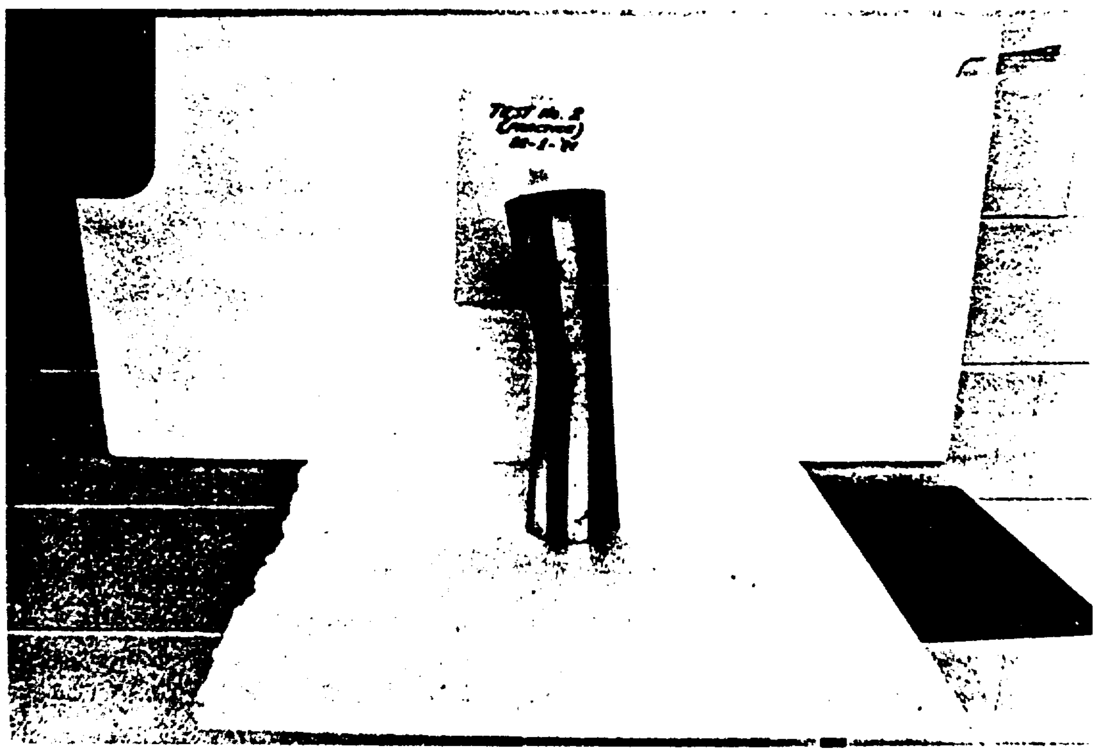
TEST ENGINEER: DALEY, AMOR

EXPERIMENT 9

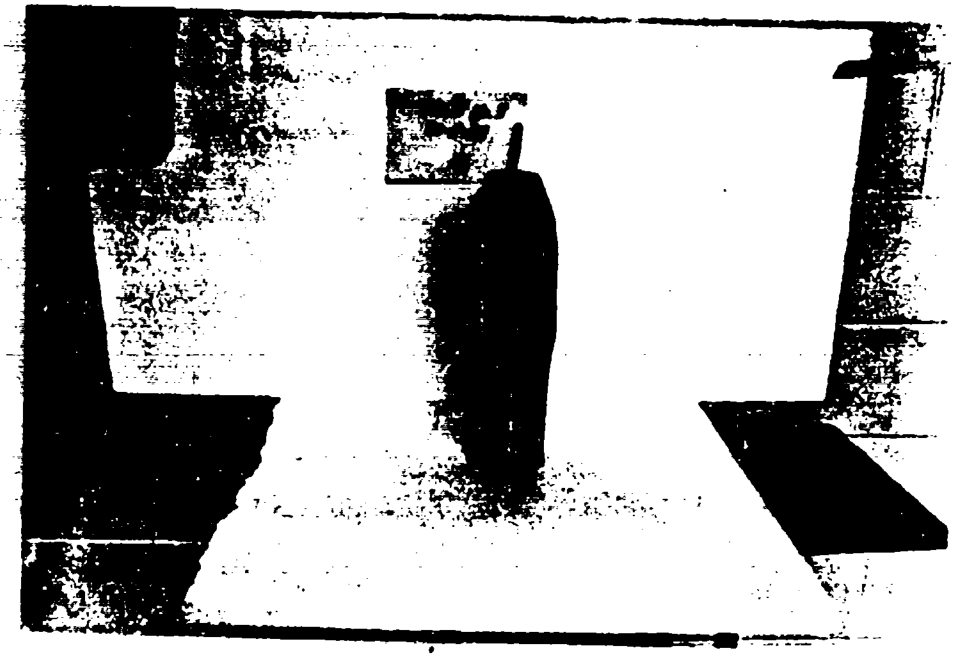
APPENDIX B

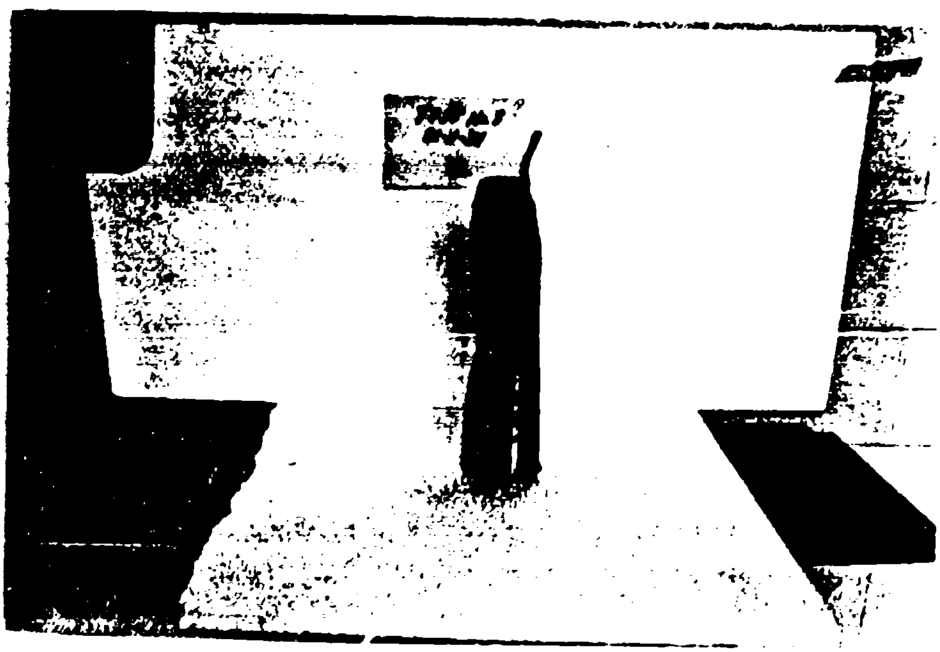
STILL PHOTOS OF IMPACTED TARGETS



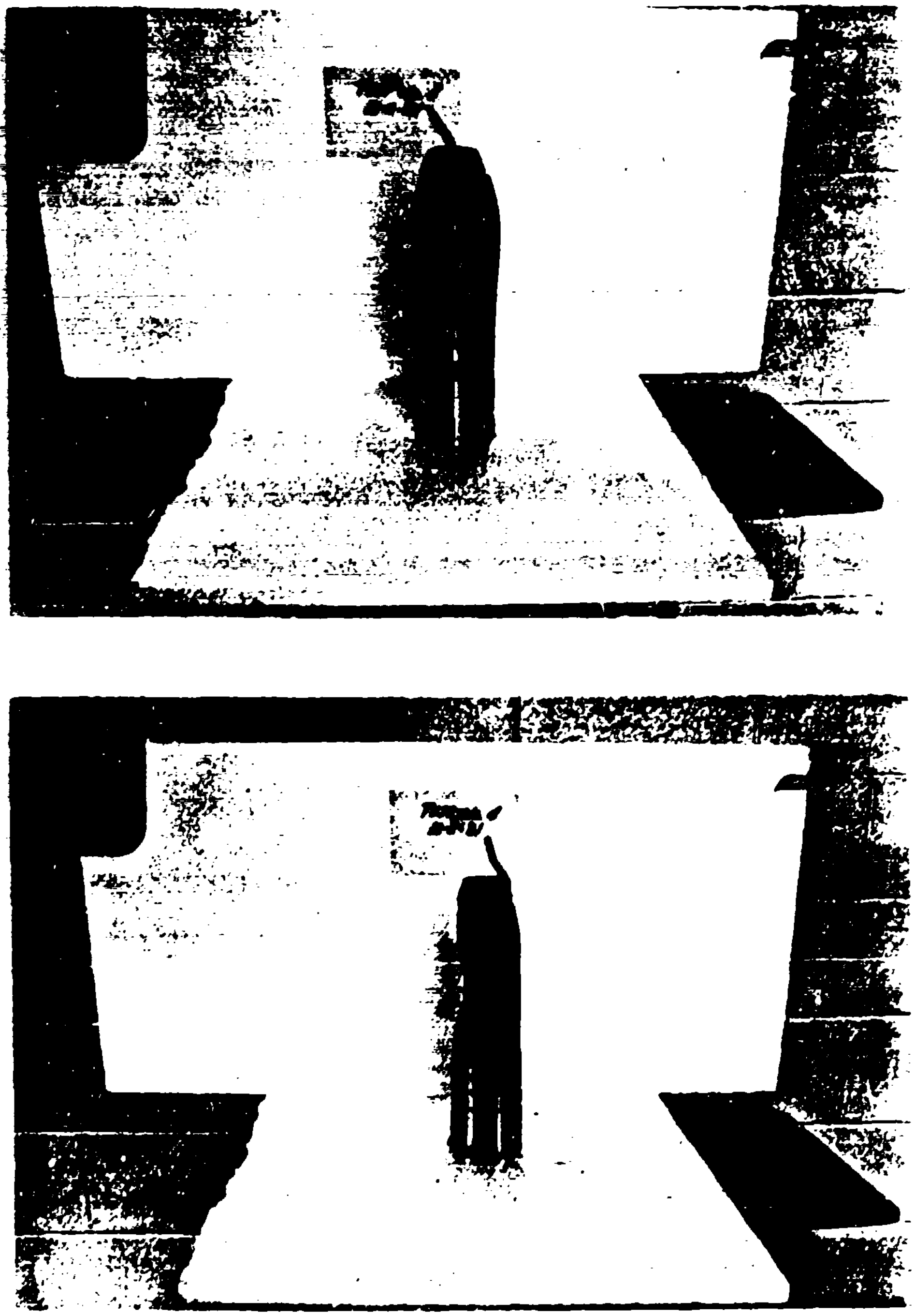


Results of Impact Experiment 2
(Top Photo Front View, Bottom Photo Side View)

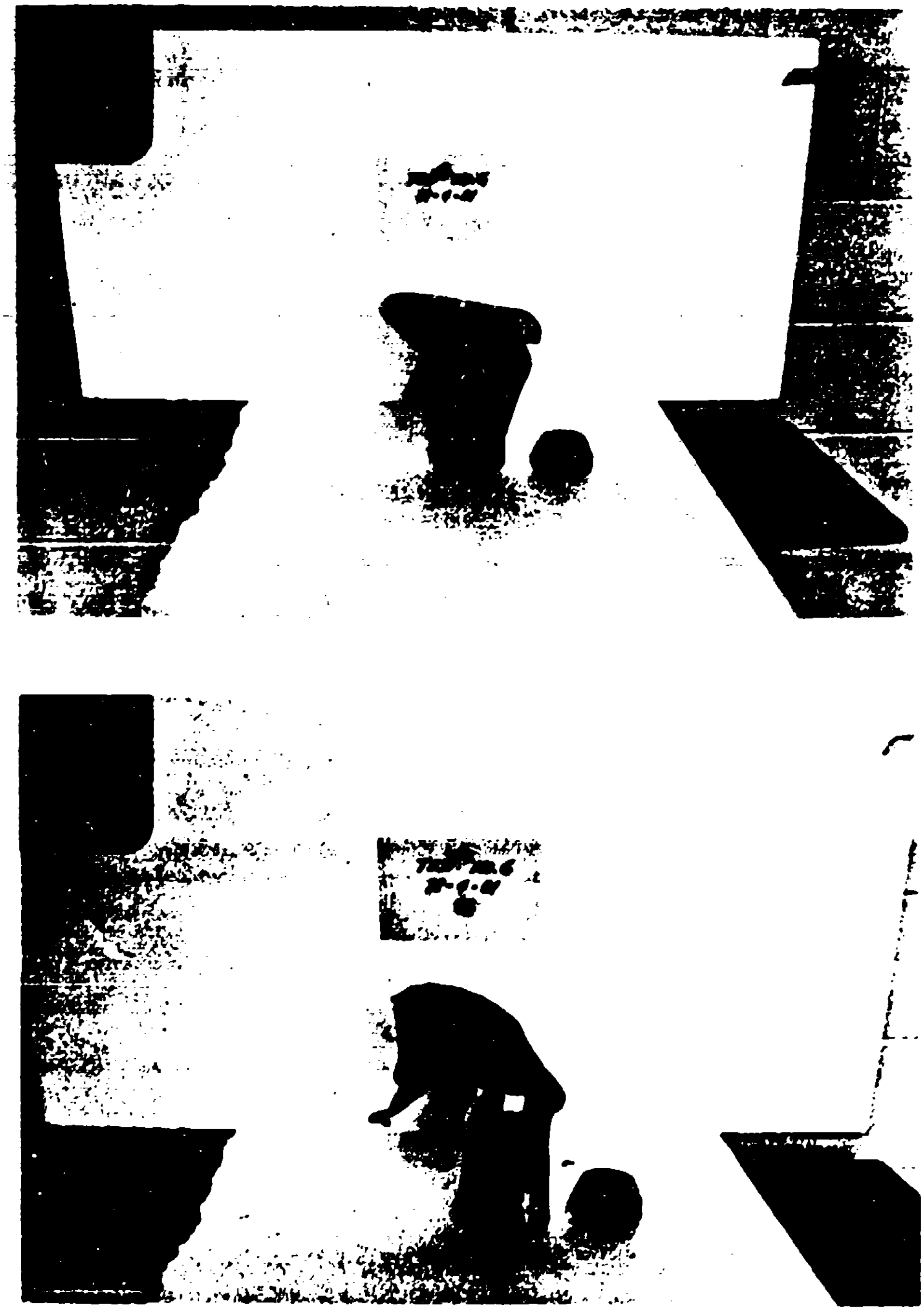




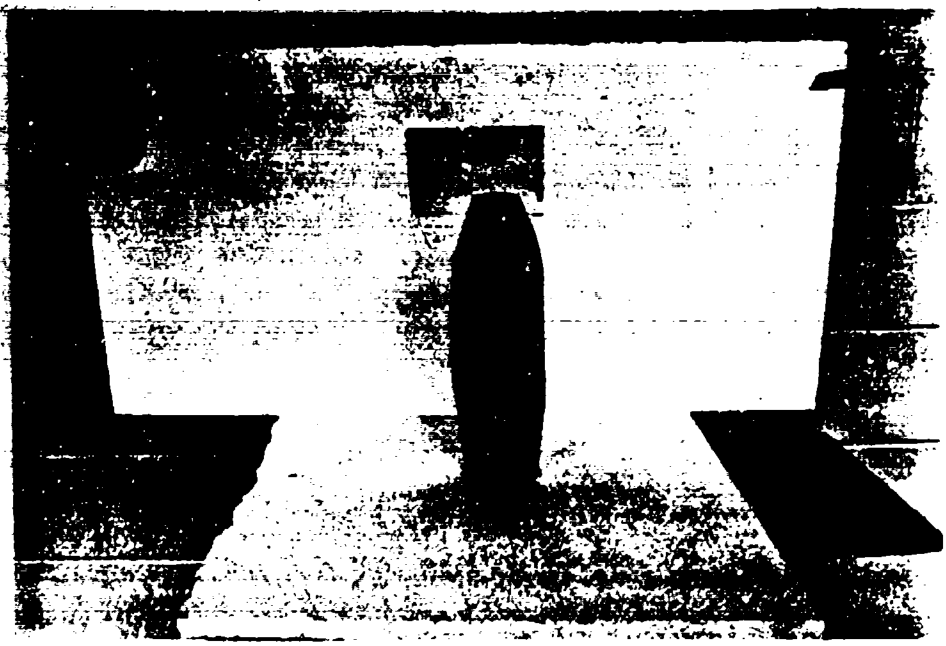
Results of Impact Experiment 3
(Top Photo Front View, Bottom Photo Side View)

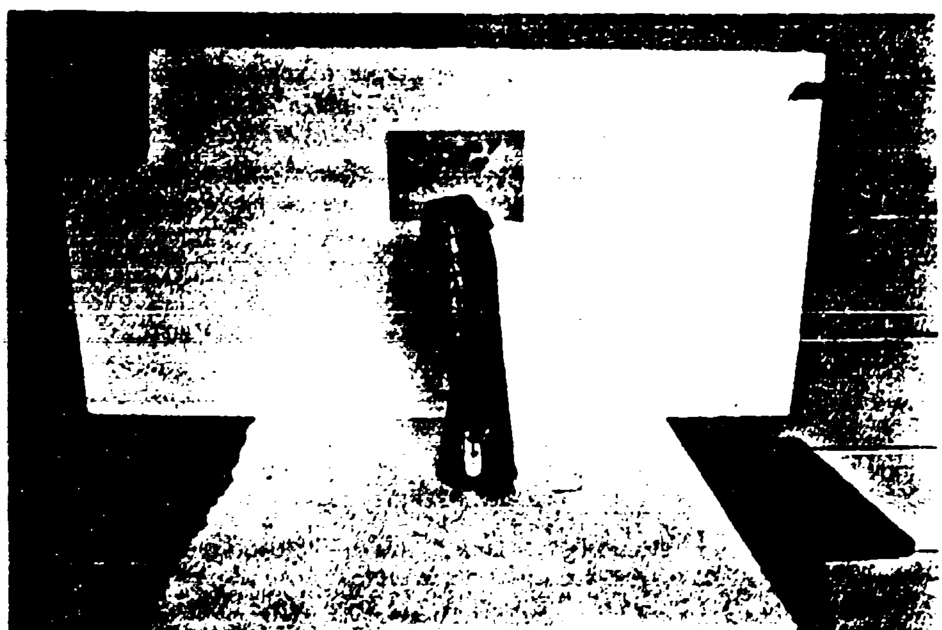


Results of Impact Experiment 4
(Top Photo Front View, Bottom Photo Side View)

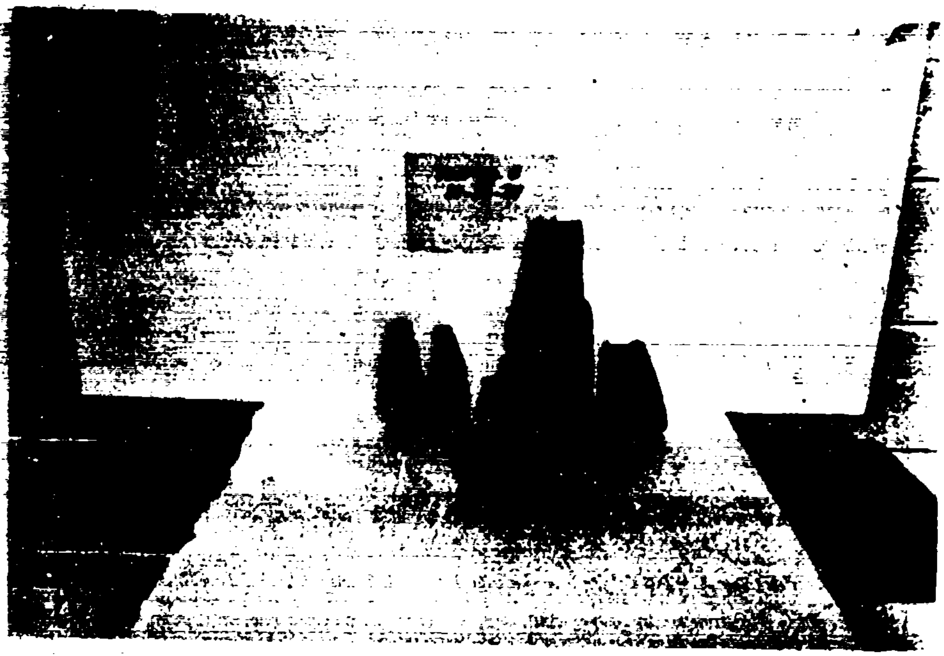


Results of Impact Experiment 6
(Top Photo Front View, Bottom Photo Side View)

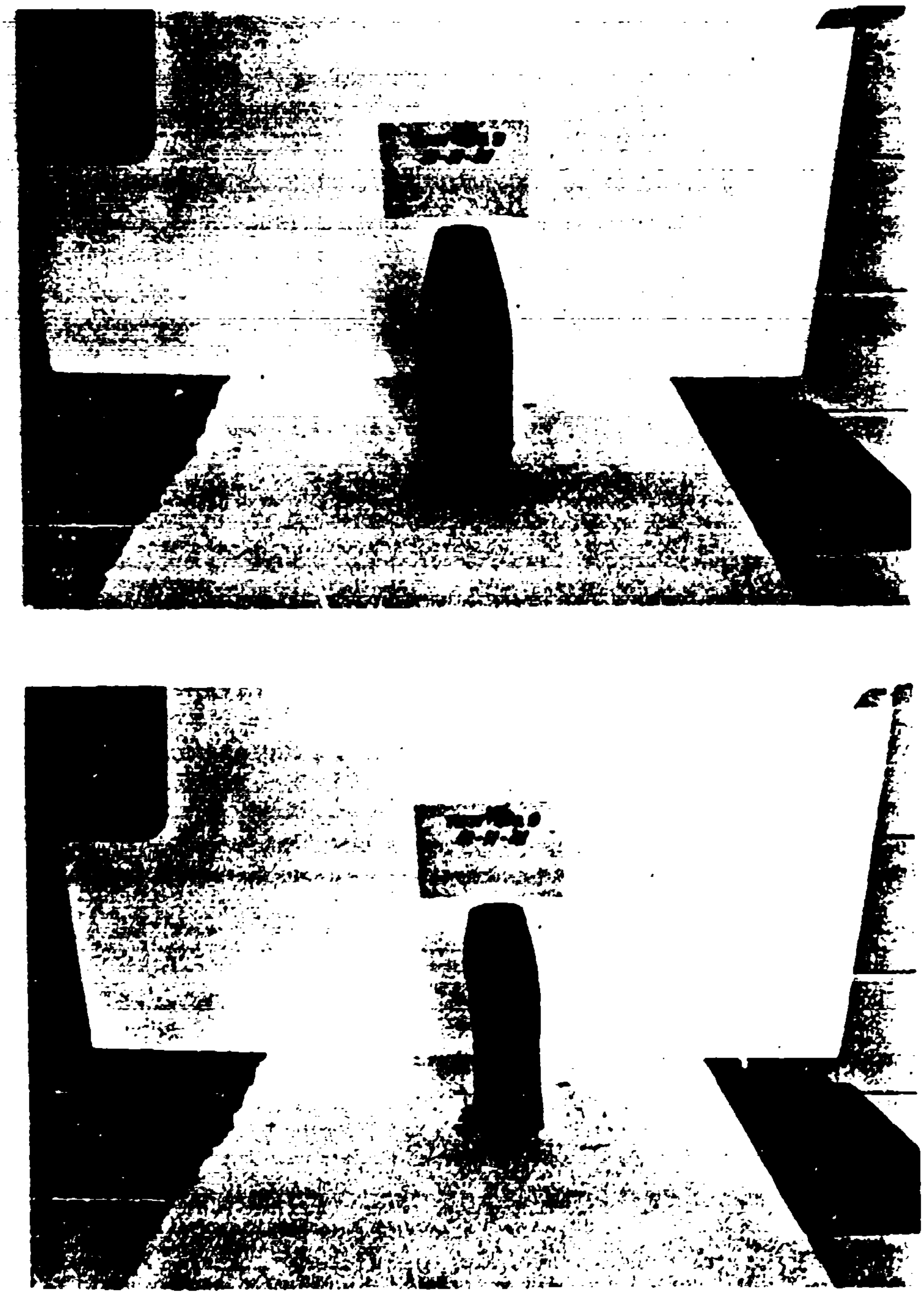




Results of Impact Experiment 7
(Top Photo Front View, Bottom Photo Side View)



Results of Impact Experiment 8



Test Results of Experiment 9
(Top Photo Front View, Bottom Photo Side View)

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